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(54) **TRIPHENYLENE SILANE HOSTS**

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H01L 51/50 (2006.01)

(52) **U.S. Cl.**
USPC **428/690**; 428/917; 313/504; 313/505; 313/506; 257/40; 257/E51.05; 257/E51.026; 257/E51.032; 548/418; 548/440

(58) **Field of Classification Search**
USPC 428/690, 917; 313/504, 505, 506; 257/40, E51.05, E51.026, E51.032; 548/418, 440
See application file for complete search history.

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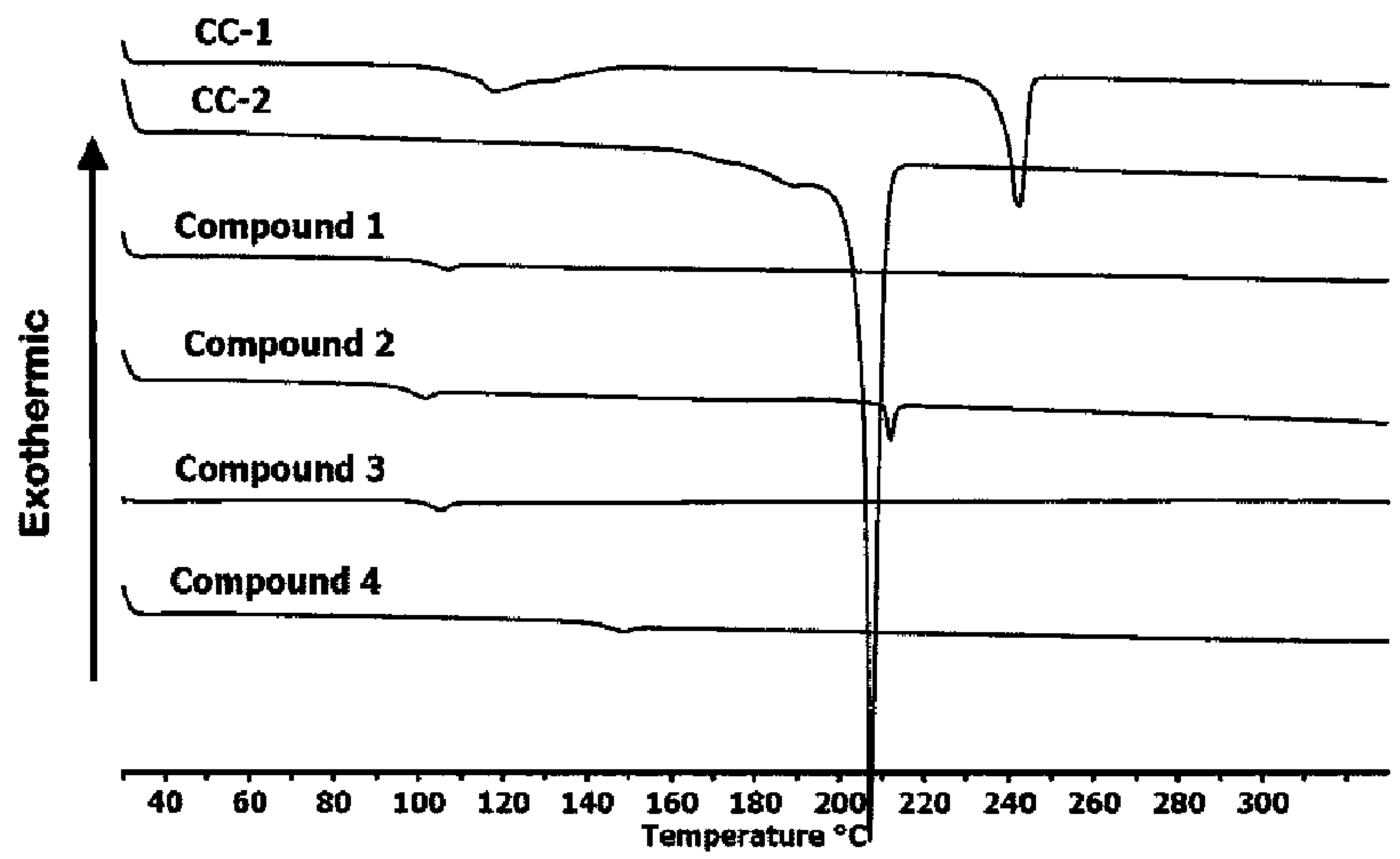
(57) **ABSTRACT**

Novel aryl silicon and aryl germanium host materials, and in particular host materials containing triphenylene and pyrene fragments, are described. These compounds improve OLED device performance when used as hosts in the emissive layer of the OLED.

23 Claims, 5 Drawing Sheets



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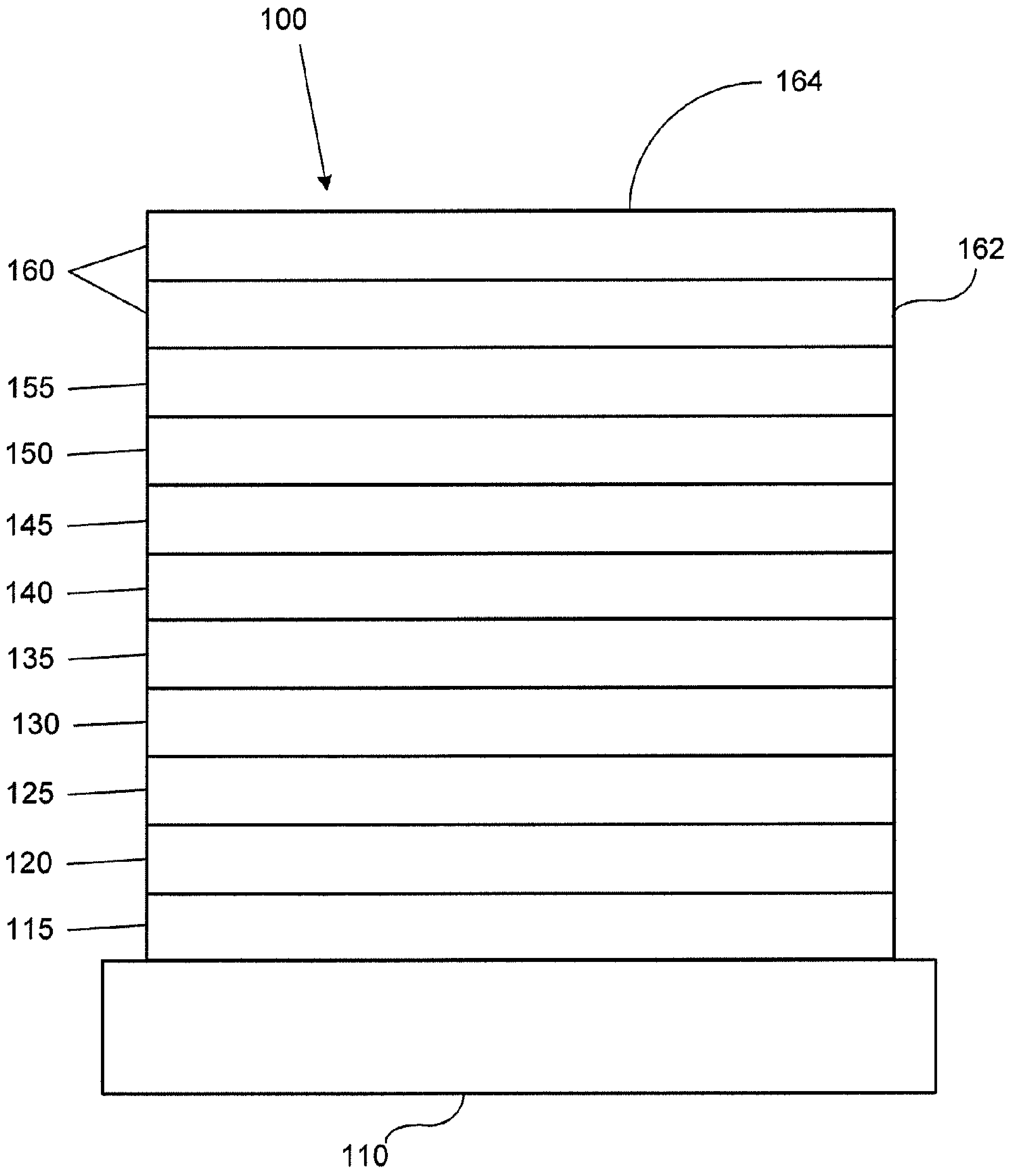


FIGURE 1

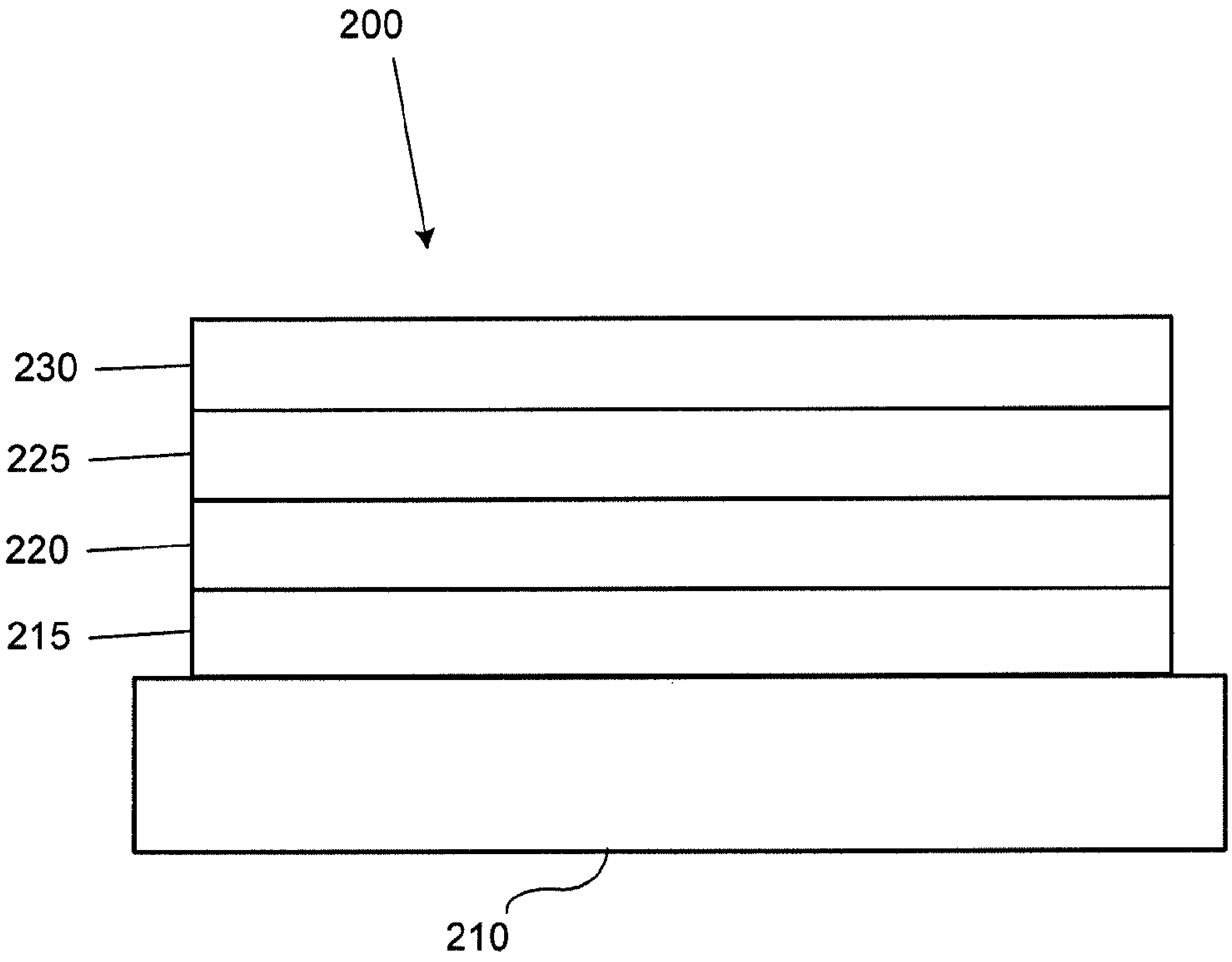
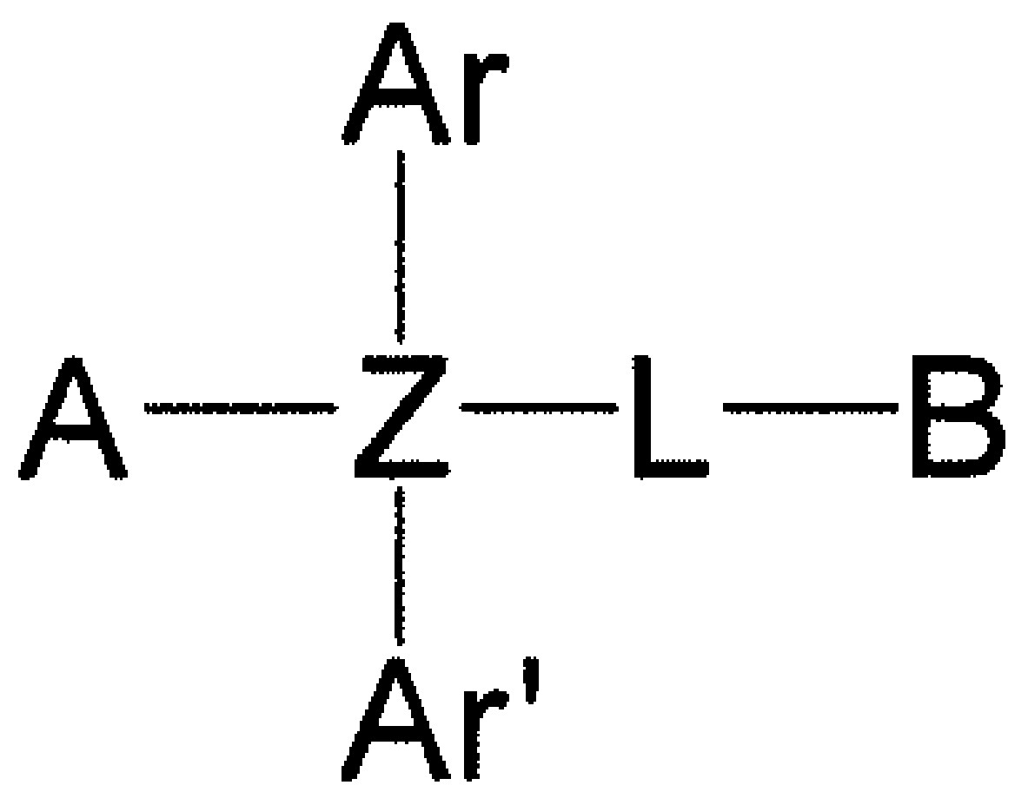


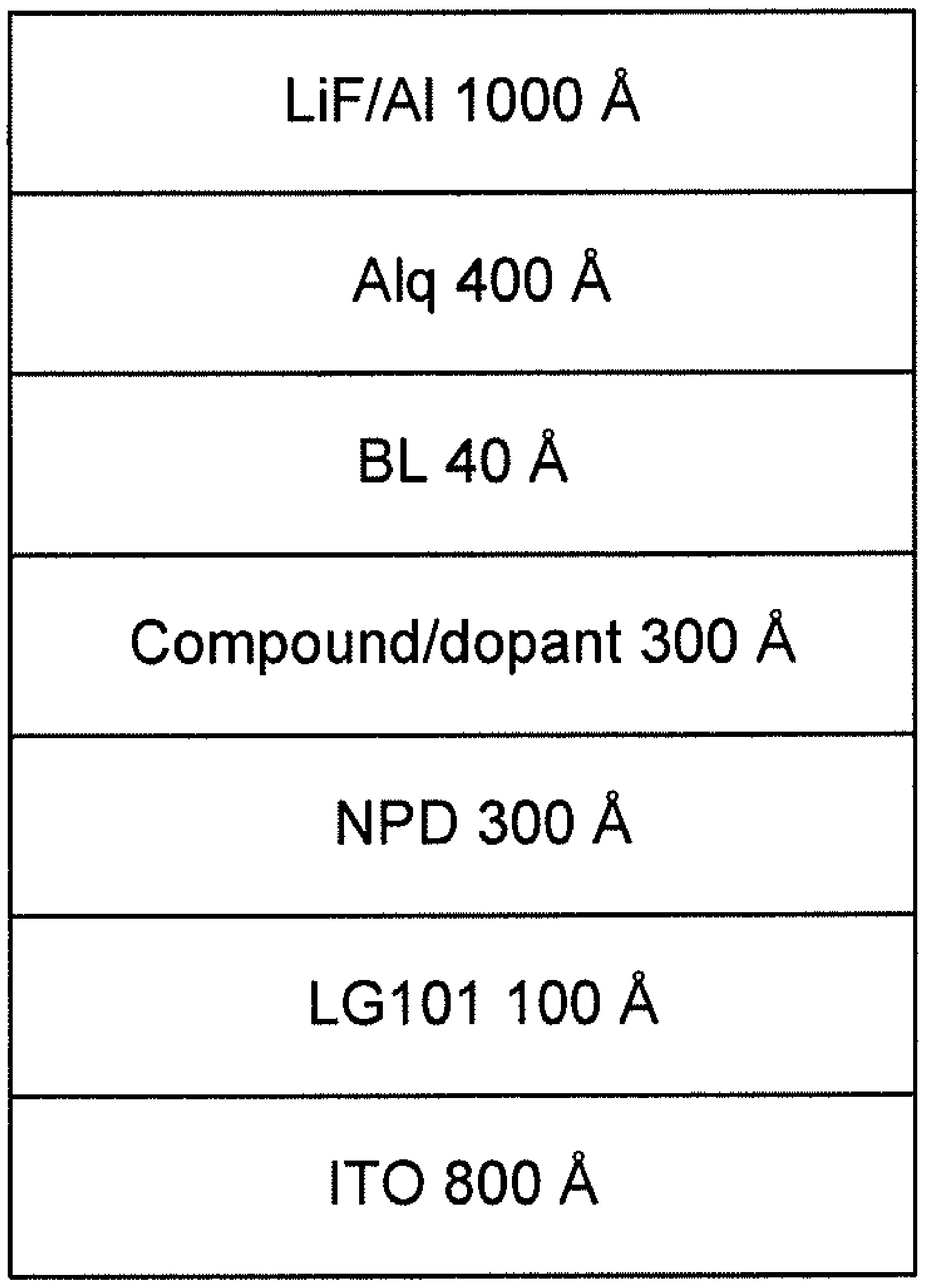
FIGURE 2



$$\mathrm{A}-\overset{\displaystyle\mathrm{Ar}\atop|}{\underset{|\atop\displaystyle\mathrm{Ar'}}{\mathrm{Z}}}-\mathrm{L}-\mathrm{B}$$

Formula I

FIGURE 3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Alq 400 Å
BL 40 Å
Compound/dopant 300 Å
NPD 300 Å
LG101 100 Å
ITO 800 Å

FIGURE 4

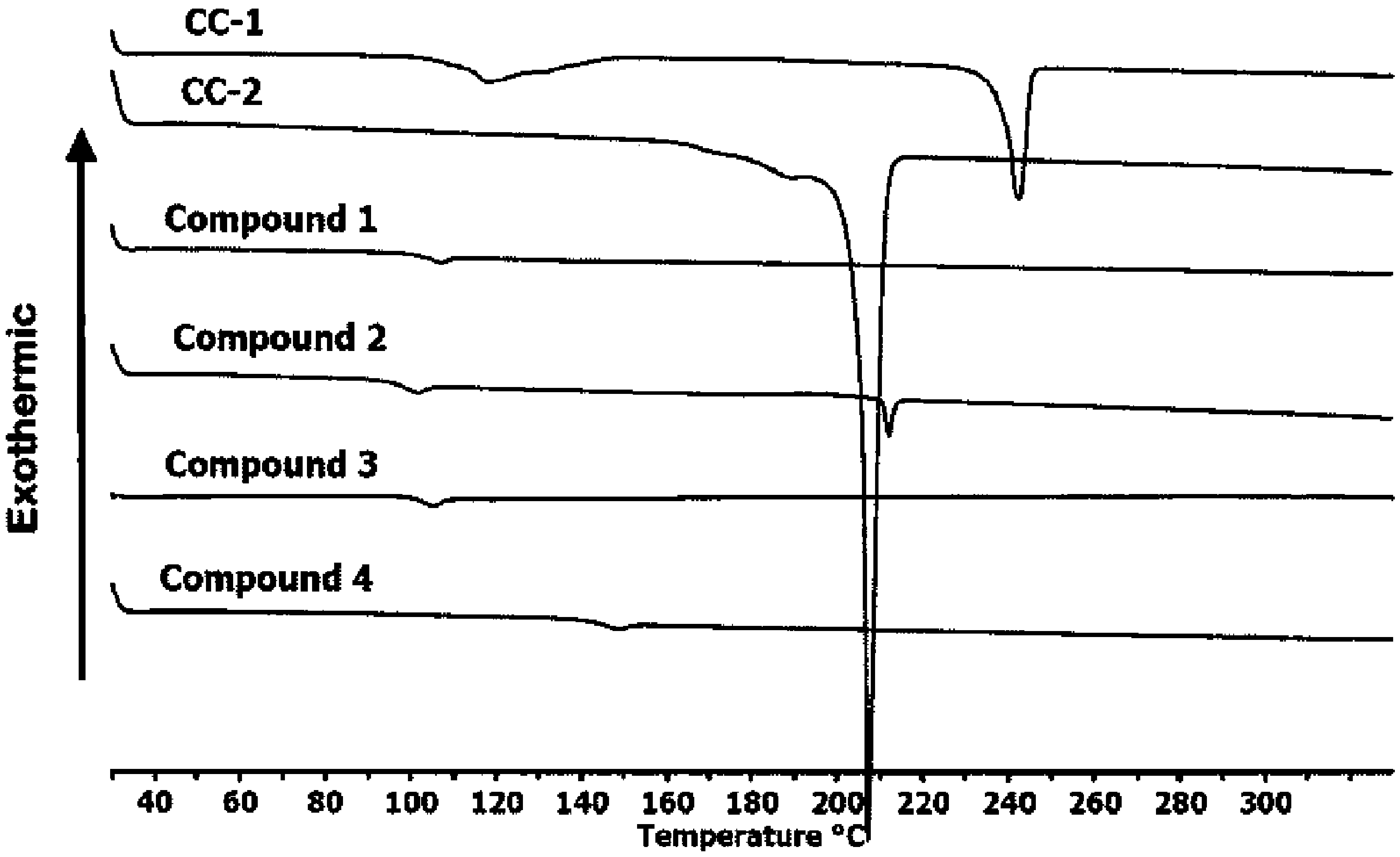

CC-1
CC-2
Compound 1
Compound 2
Compound 3
Compound 4
Exothermic
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Temperature °C

FIGURE 5

TRIPHENYLENE SILANE HOSTS

The claimed invention was made by, on behalf of, and/or in connection with one or more of the following parties to a joint university corporation research agreement: Regents of the University of Michigan, Princeton University, The University of Southern California, and the Universal Display Corporation. The agreement was in effect on and before the date the claimed invention was made, and the claimed invention was made as a result of activities undertaken within the scope of the agreement.

FIELD OF THE INVENTION

The present invention relates to compounds suitable for use as host materials in OLEDs, specifically compounds comprising arylgermane and arylsilane groups.

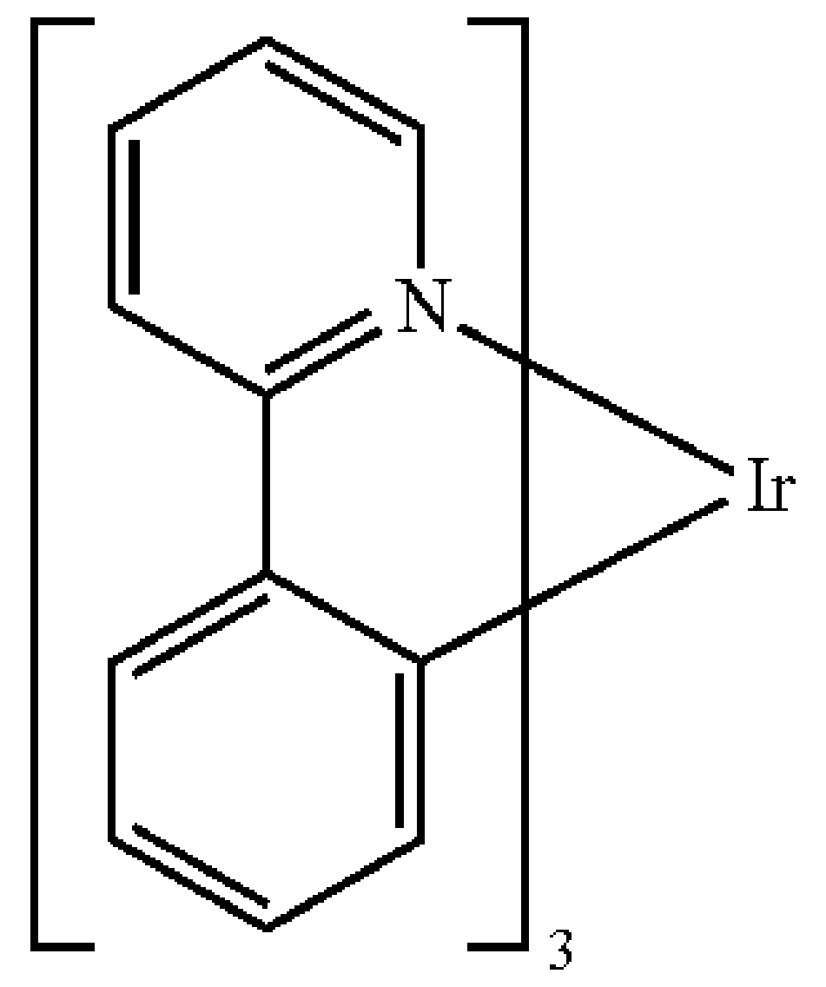
BACKGROUND

Opto-electronic devices that make use of organic materials are becoming increasingly desirable for a number of reasons. Many of the materials used to make such devices are relatively inexpensive, so organic opto-electronic devices have the potential for cost advantages over inorganic devices. In addition, the inherent properties of organic materials, such as their flexibility, may make them well suited for particular applications such as fabrication on a flexible substrate. Examples of organic opto-electronic devices include organic light emitting devices (OLEDs), organic phototransistors, organic photovoltaic cells, and organic photodetectors. For OLEDs, the organic materials may have performance advantages over conventional materials. For example, the wavelength at which an organic emissive layer emits light may generally be readily tuned with appropriate dopants.

OLEDs make use of thin organic films that emit light when voltage is applied across the device. OLEDs are becoming an increasingly interesting technology for use in applications such as flat panel displays, illumination, and backlighting. Several OLED materials and configurations are described in U.S. Pat. Nos. 5,844,363, 6,303,238, and 5,707,745, which are incorporated herein by reference in their entirety.

One application for phosphorescent emissive molecules is a full color display. Industry standards for such a display call for pixels adapted to emit particular colors, referred to as "saturated" colors. In particular, these standards call for saturated red, green, and blue pixels. Color may be measured using CIE coordinates, which are well known to the art.

One example of a green emissive molecule is tris(2-phenylpyridine)iridium, denoted Ir(ppy)$_3$, which has the following structure:



In this, and later figures herein, we depict the dative bond from nitrogen to metal (here, Ir) as a straight line.

As used herein, the term "organic" includes polymeric materials as well as small molecule organic materials that may be used to fabricate organic opto-electronic devices. "Small molecule" refers to any organic material that is not a polymer, and "small molecules" may actually be quite large. Small molecules may include repeat units in some circumstances. For example, using a long chain alkyl group as a substituent does not remove a molecule from the "small molecule" class. Small molecules may also be incorporated into polymers, for example as a pendent group on a polymer backbone or as a part of the backbone. Small molecules may also serve as the core moiety of a dendrimer, which consists of a series of chemical shells built on the core moiety. The core moiety of a dendrimer may be a fluorescent or phosphorescent small molecule emitter. A dendrimer may be a "small molecule," and it is believed that all dendrimers currently used in the field of OLEDs are small molecules.

As used herein, "top" means furthest away from the substrate, while "bottom" means closest to the substrate. Where a first layer is described as "disposed over" a second layer, the first layer is disposed further away from substrate. There may be other layers between the first and second layer, unless it is specified that the first layer is "in contact with" the second layer. For example, a cathode may be described as "disposed over" an anode, even though there are various organic layers in between.

As used herein, "solution processible" means capable of being dissolved, dispersed, or transported in and/or deposited from a liquid medium, either in solution or suspension form.

A ligand may be referred to as "photoactive" when it is believed that the ligand directly contributes to the photoactive properties of an emissive material. A ligand may be referred to as "ancillary" when it is believed that the ligand does not contribute to the photoactive properties of an emissive material, although an ancillary ligand may alter the properties of a photoactive ligand.

As used herein, and as would be generally understood by one skilled in the art, a first "Highest Occupied Molecular Orbital" (HOMO) or "Lowest Unoccupied Molecular Orbital" (LUMO) energy level is "greater than" or "higher than" a second HOMO or LUMO energy level if the first energy level is closer to the vacuum energy level. Since ionization potentials (IP) are measured as a negative energy relative to a vacuum level, a higher HOMO energy level corresponds to an IP having a smaller absolute value (an IP that is less negative). Similarly, a higher LUMO energy level corresponds to an electron affinity (EA) having a smaller absolute value (an EA that is less negative). On a conventional energy level diagram, with the vacuum level at the top, the LUMO energy level of a material is higher than the HOMO energy level of the same material. A "higher" HOMO or LUMO energy level appears closer to the top of such a diagram than a "lower" HOMO or LUMO energy level.

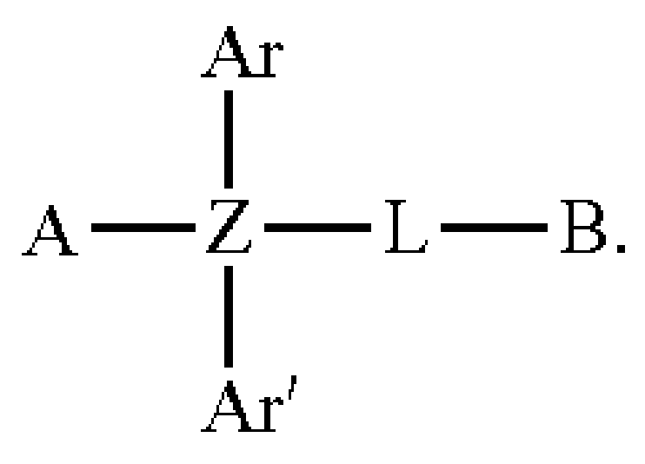
As used herein, and as would be generally understood by one skilled in the art, a first work function is "greater than" or "higher than" a second work function if the first work function has a higher absolute value. Because work functions are generally measured as negative numbers relative to vacuum level, this means that a "higher" work function is more negative. On a conventional energy level diagram, with the vacuum level at the top, a "higher" work function is illustrated as further away from the vacuum level in the downward direction. Thus, the definitions of HOMO and LUMO energy levels follow a different convention than work functions.

More details on OLEDs, and the definitions described above, can be found in U.S. Pat. No. 7,279,704, which is incorporated herein by reference in its entirety.

SUMMARY OF THE INVENTION

In one aspect, a compound having the Formula I is provided:

Formula I

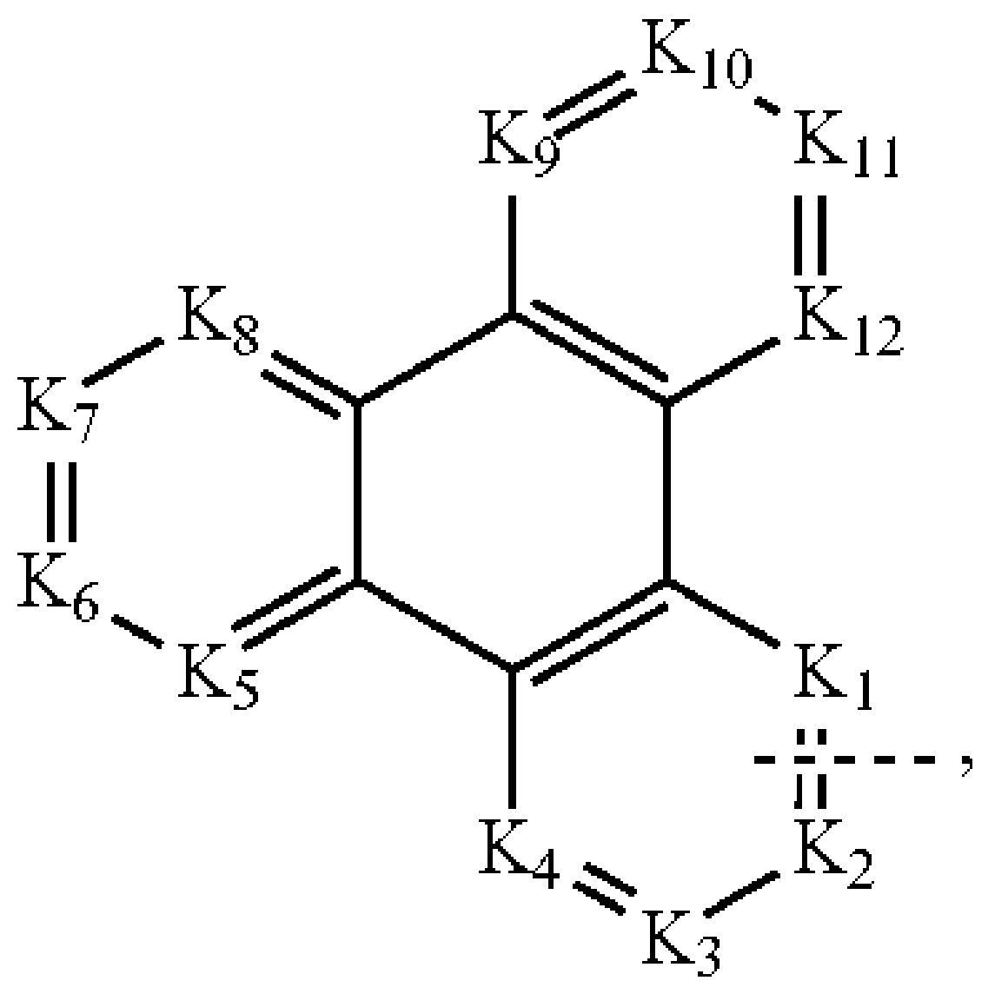


$$\begin{array}{c} Ar \\ | \\ A—Z—L—B. \\ | \\ Ar' \end{array}$$

In the compound of Formula I, Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, naphthalene, dibenzothiophene and dibenzofuran, which are optionally further substituted. Z is selected from Si and Ge. L is a single bond or comprises an aryl or heteroaryl group having from 5-20 carbon atoms, which is optionally further substituted. A is a group directly bonded to Z and is selected from the group consisting of triphenylene, tetraphenylene, pyrene, naphthalene, fluoranthene, chrysene, phenanthrene, azatriphenylene, azatetraphenylene, azapyrene, azanaphthalene, azafluoranthene, azachrysene, azaphenanthrene, and combinations thereof, which are optionally further substituted with one or more groups selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof.

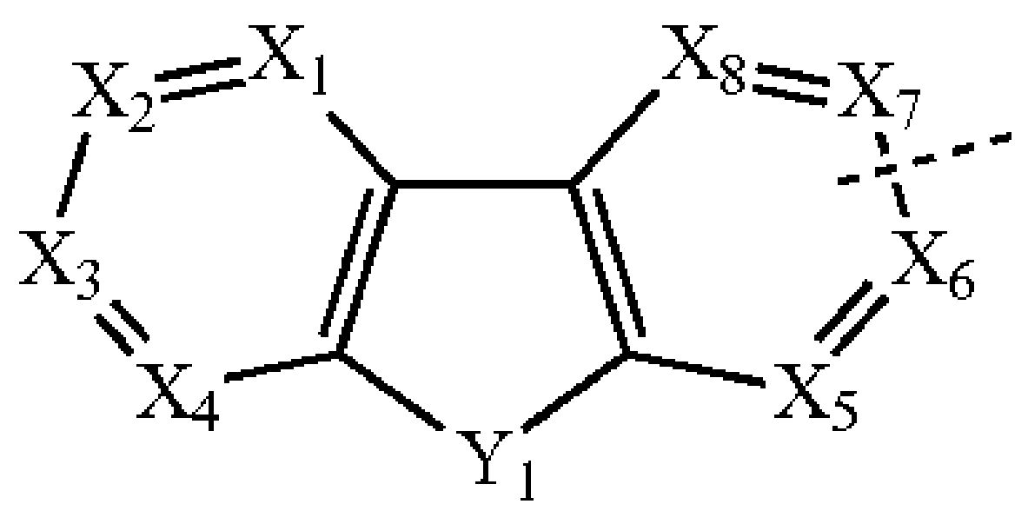
B contains a group selected from the group consisting of carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene, azadibenzoselenophene, and combinations thereof, which are optionally further substituted with one or more groups selected from hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein the substitution is optionally fused to the carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene or azadibenzoselenophene group.

In one aspect, A is



wherein K_1 to K_{12} are independently selected from N and C—R', and wherein R' is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof.

In one aspect, B is selected from the group consisting of:



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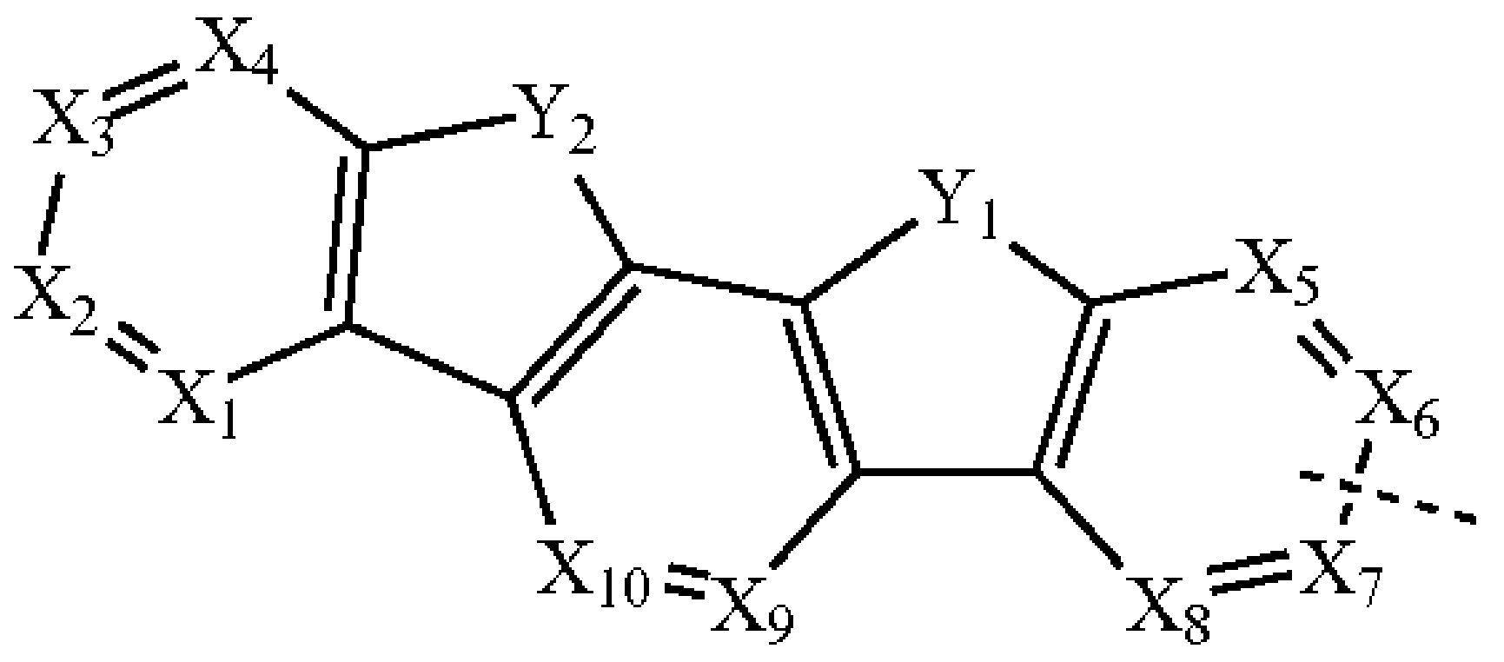

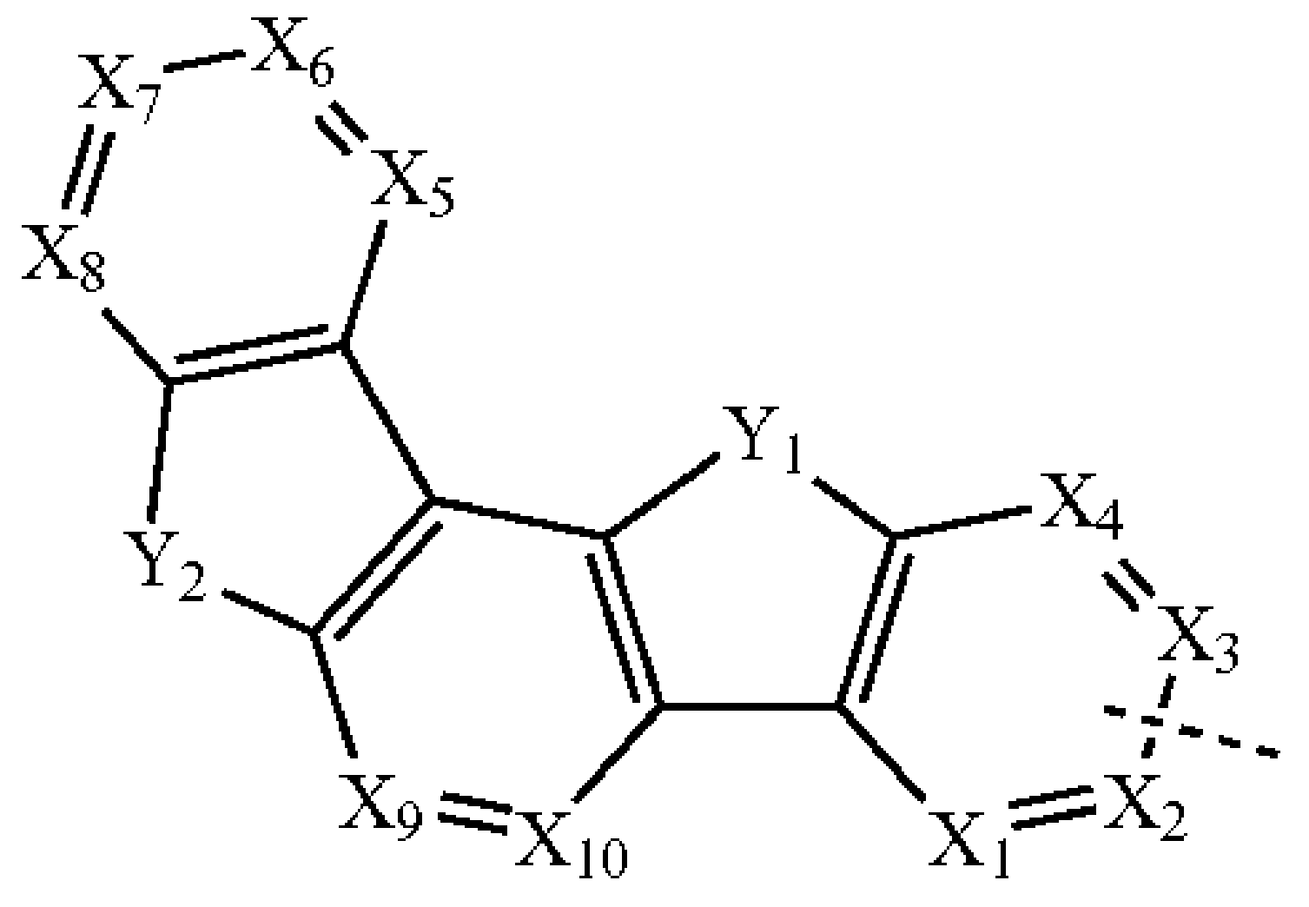

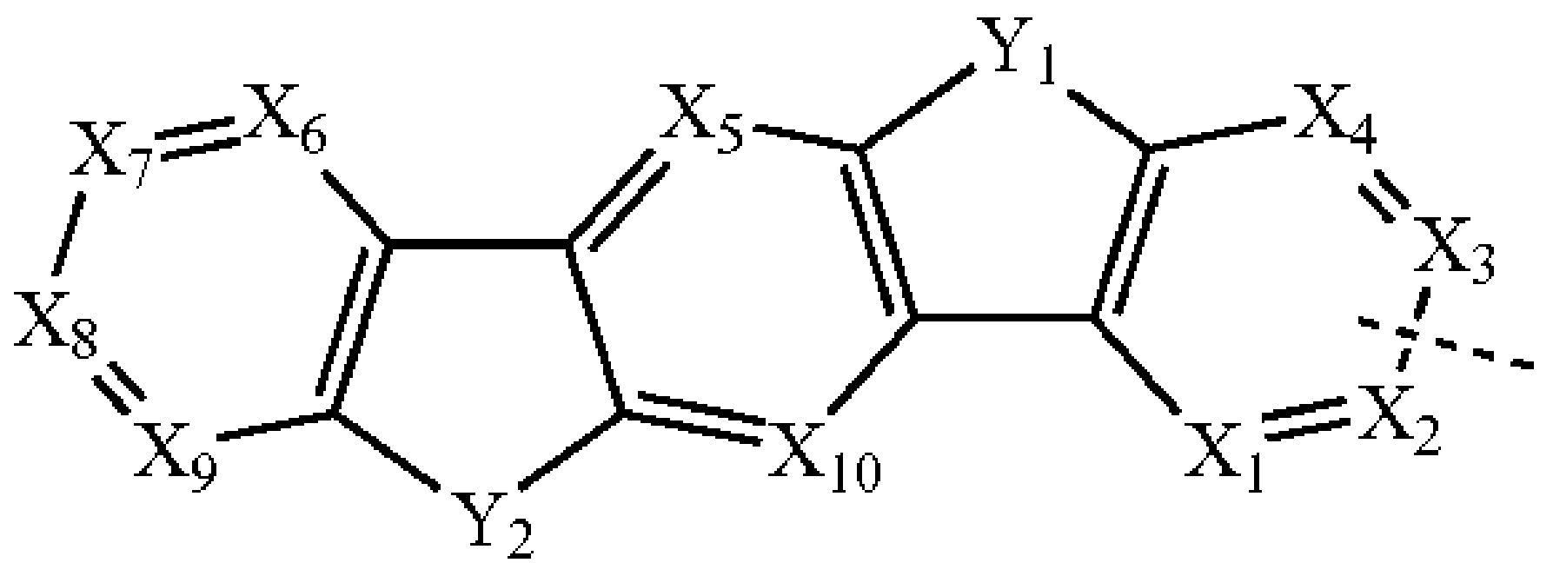

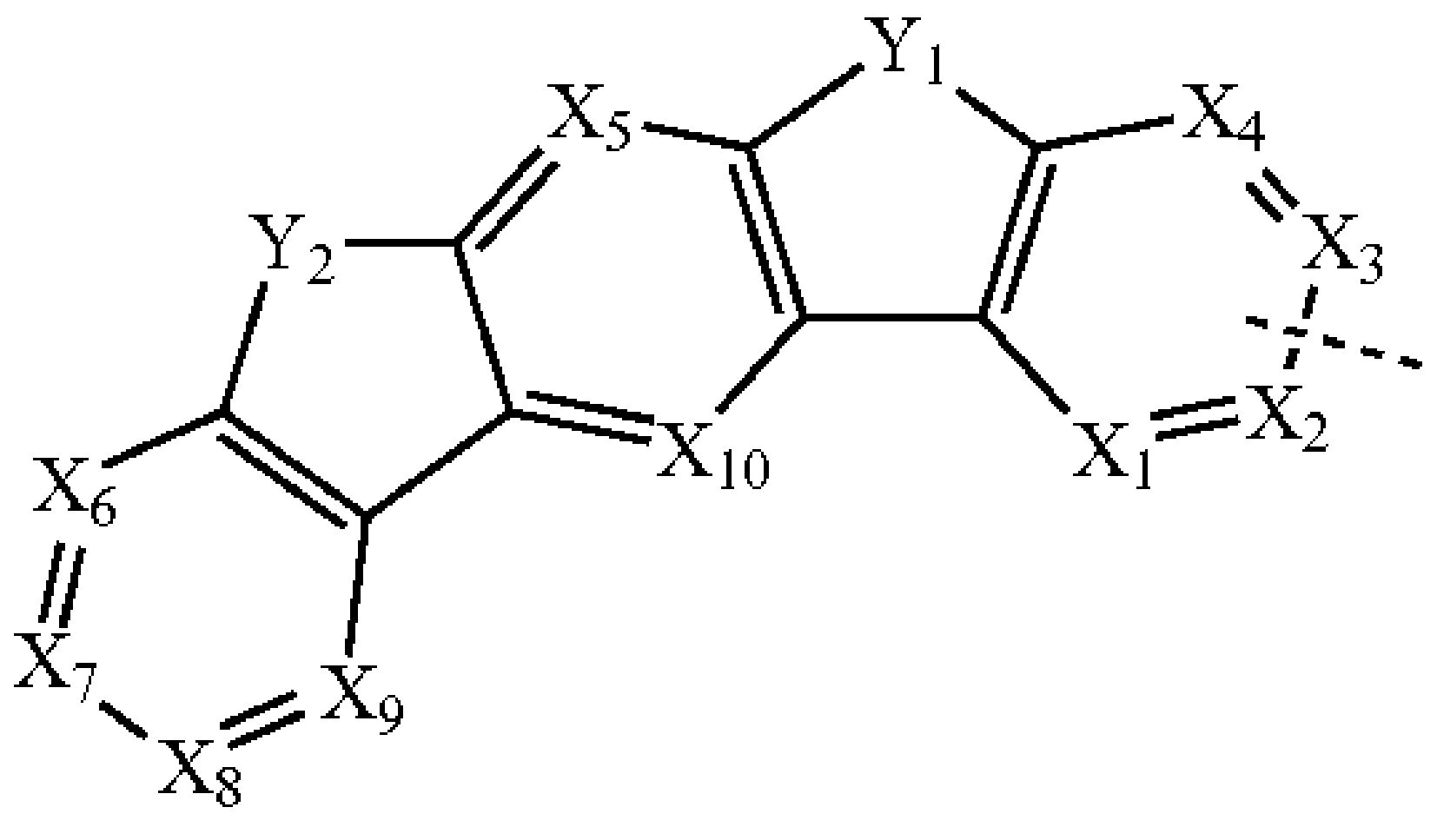

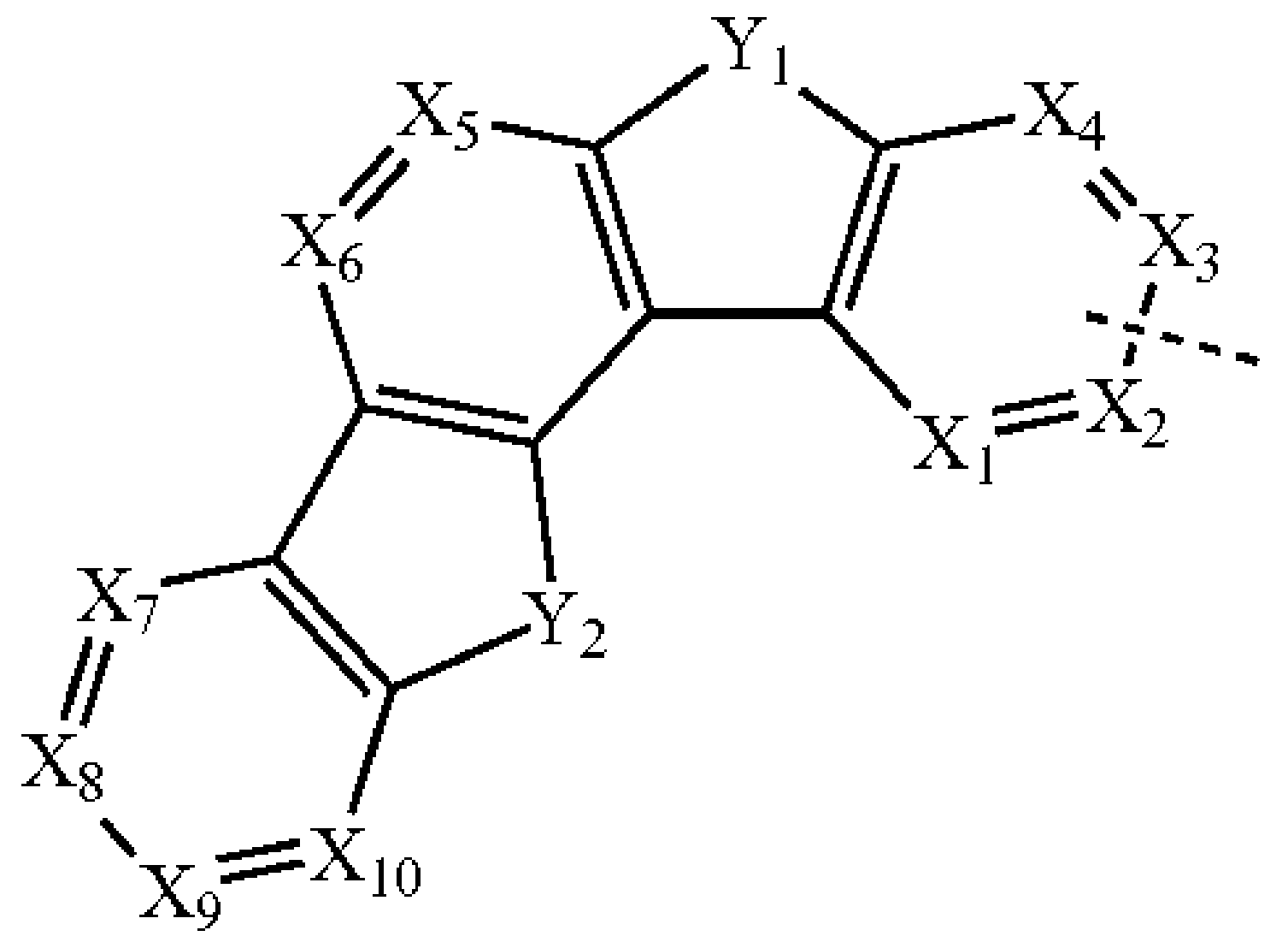

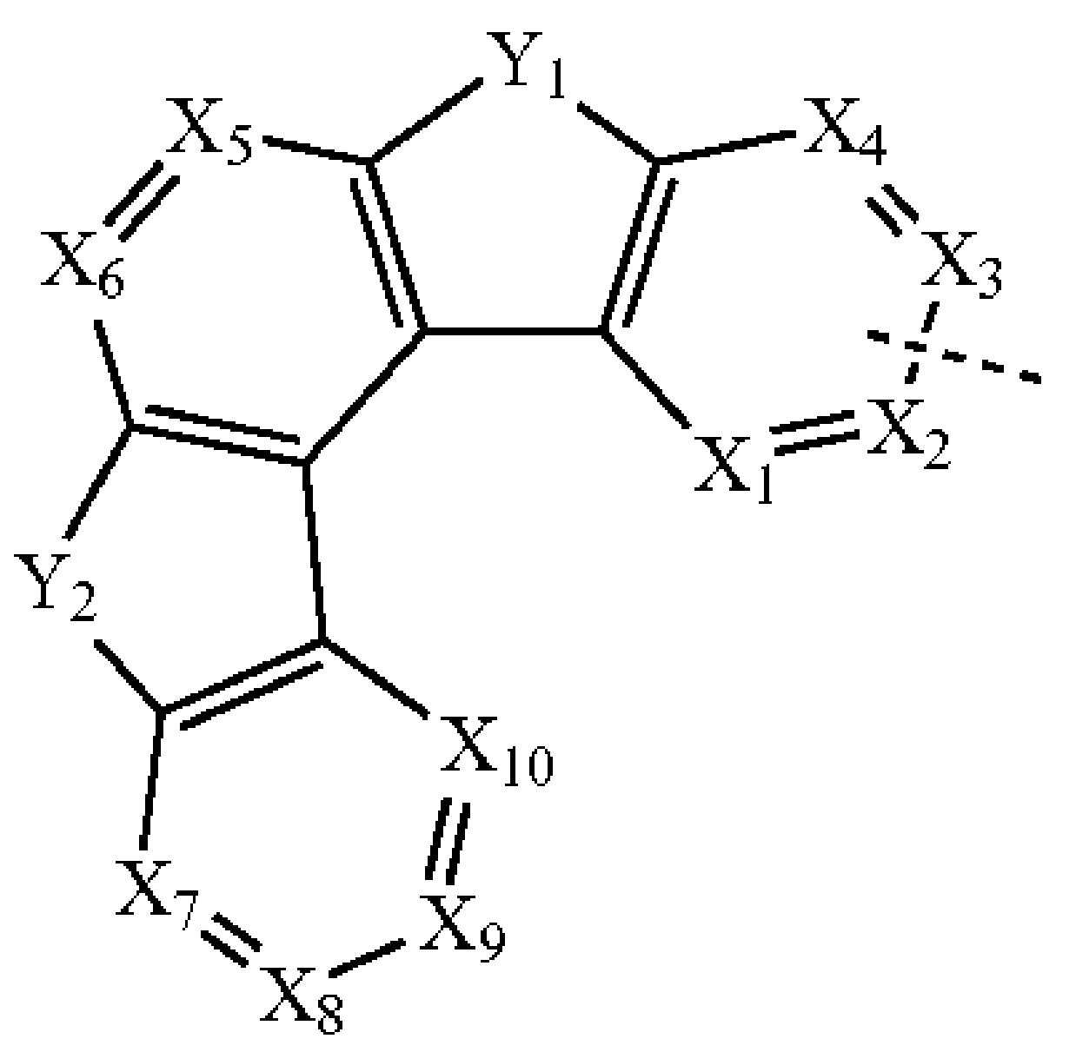

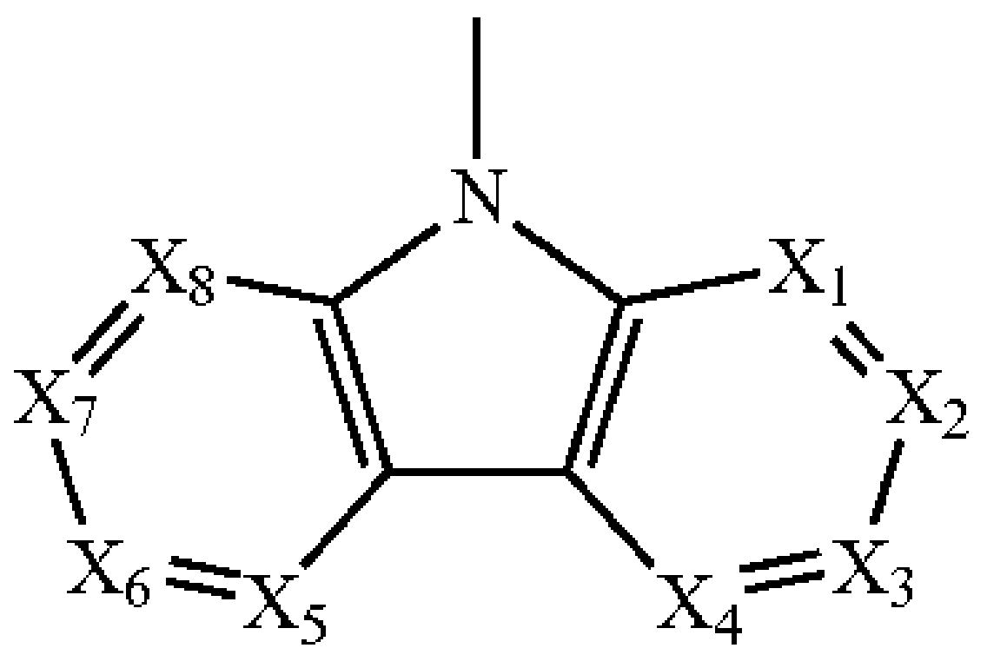

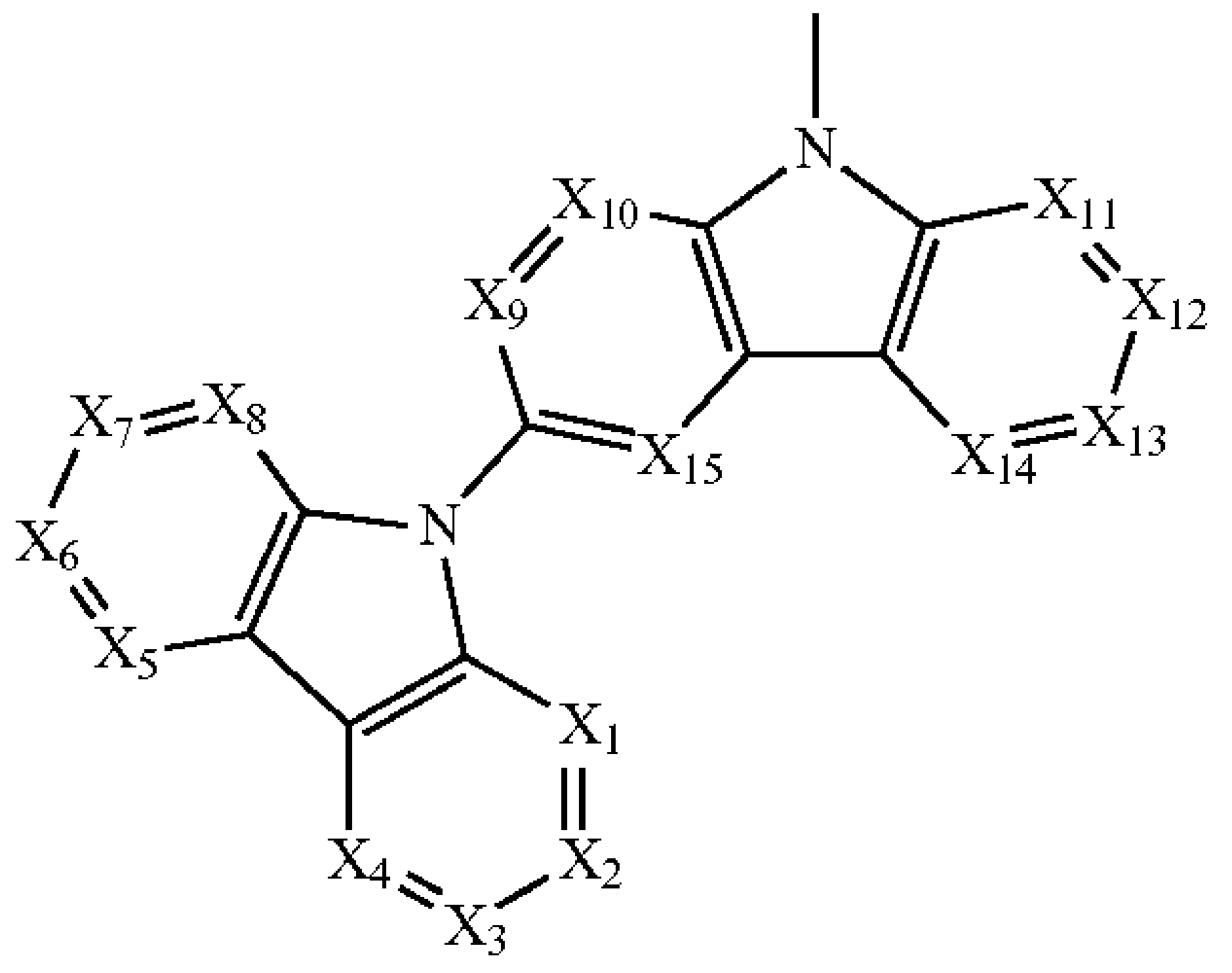

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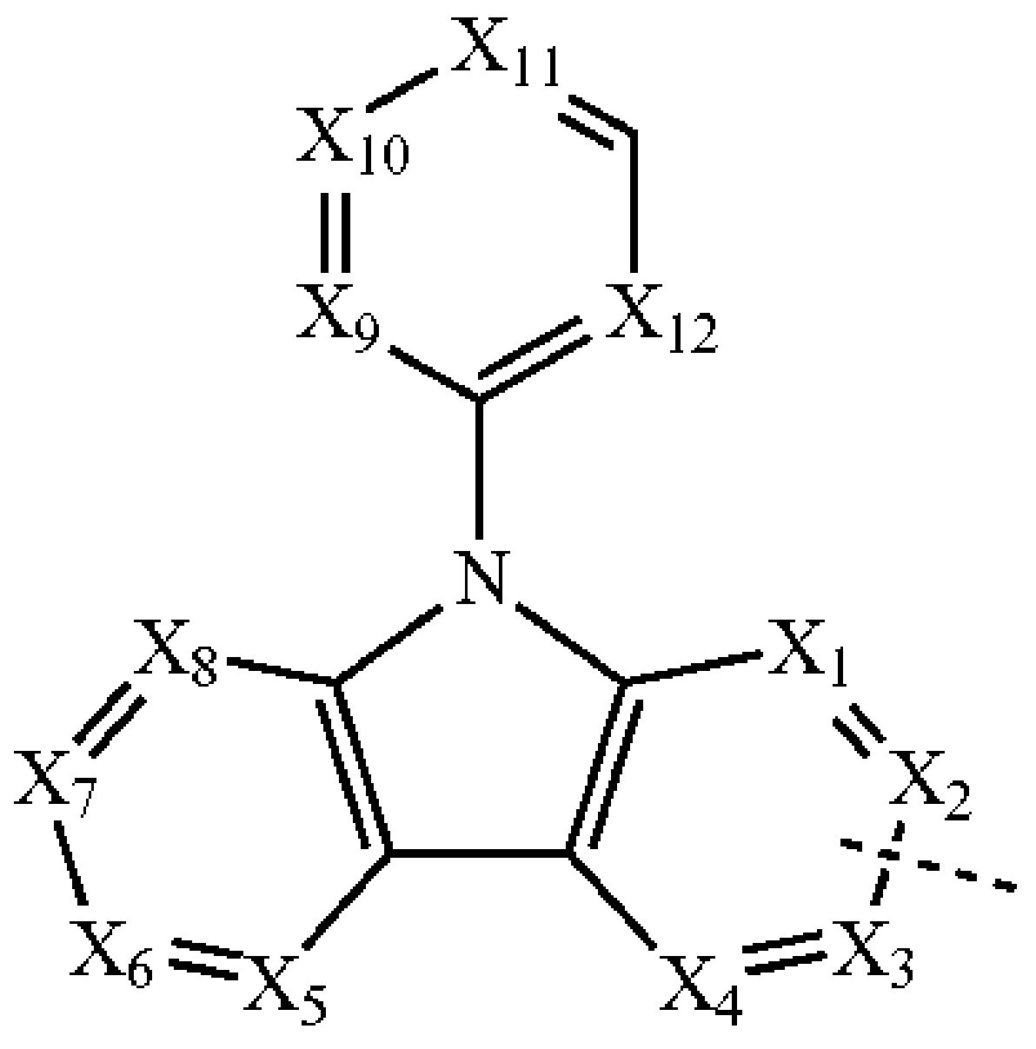
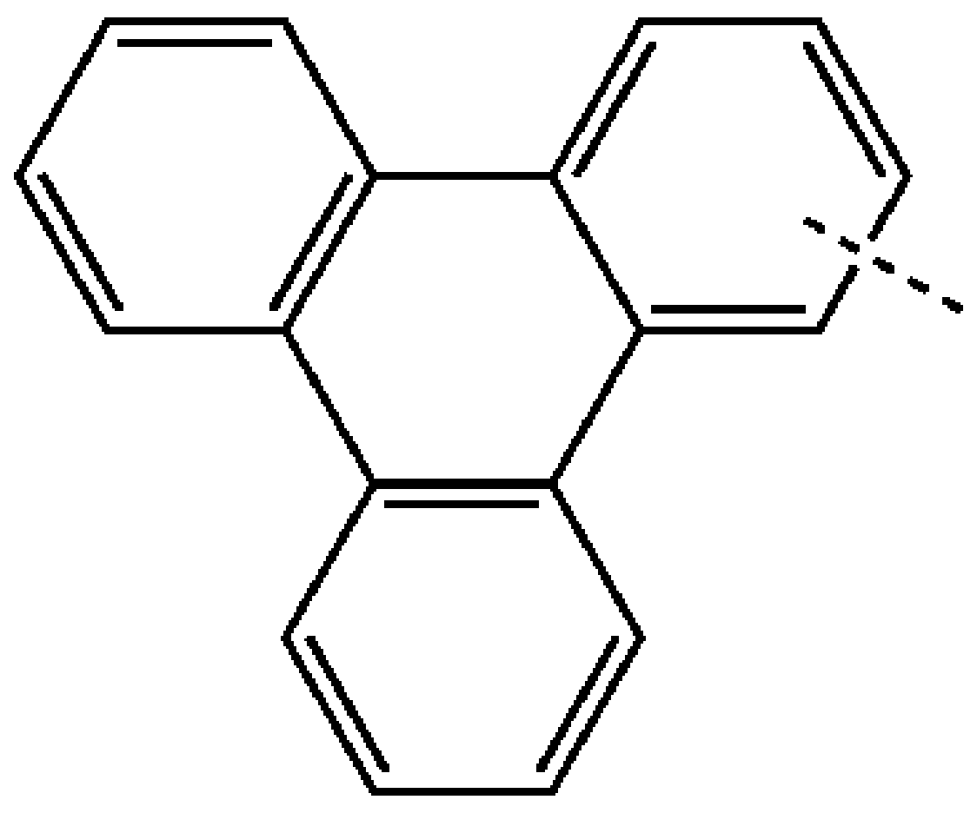
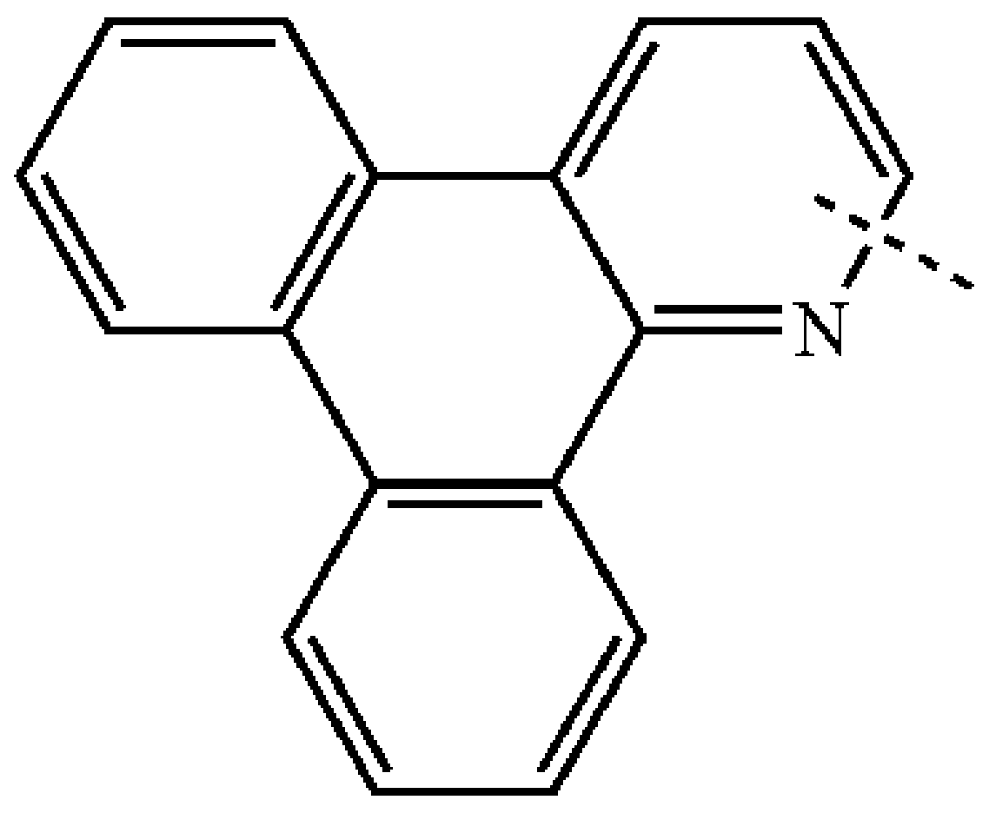
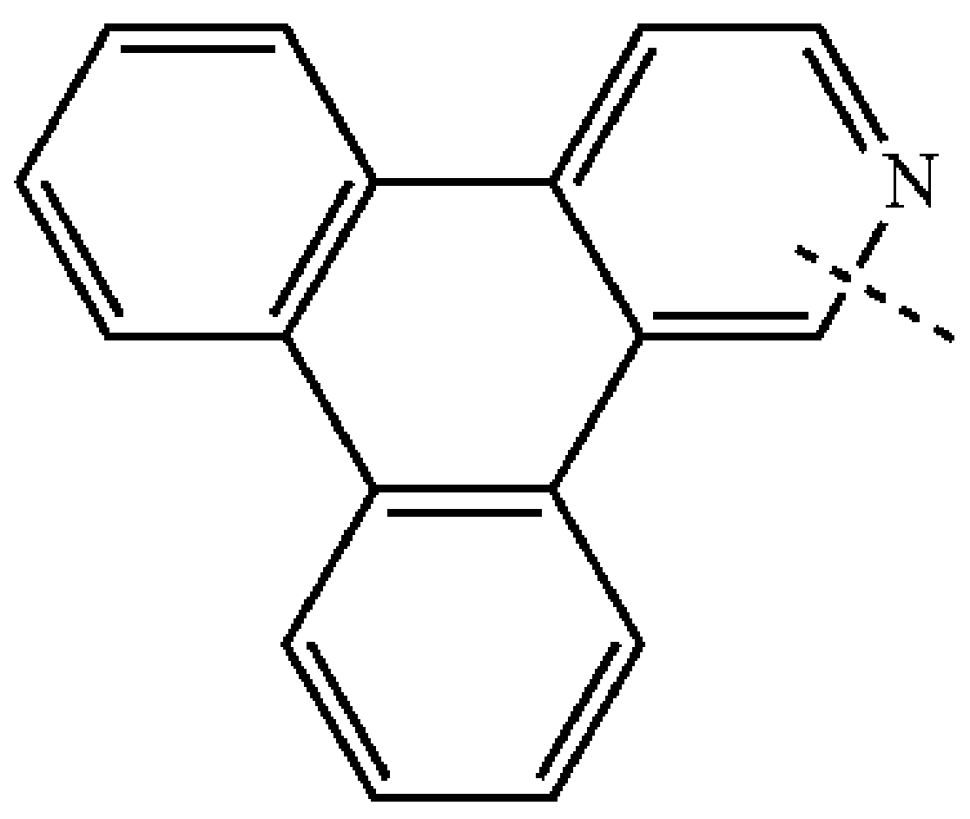


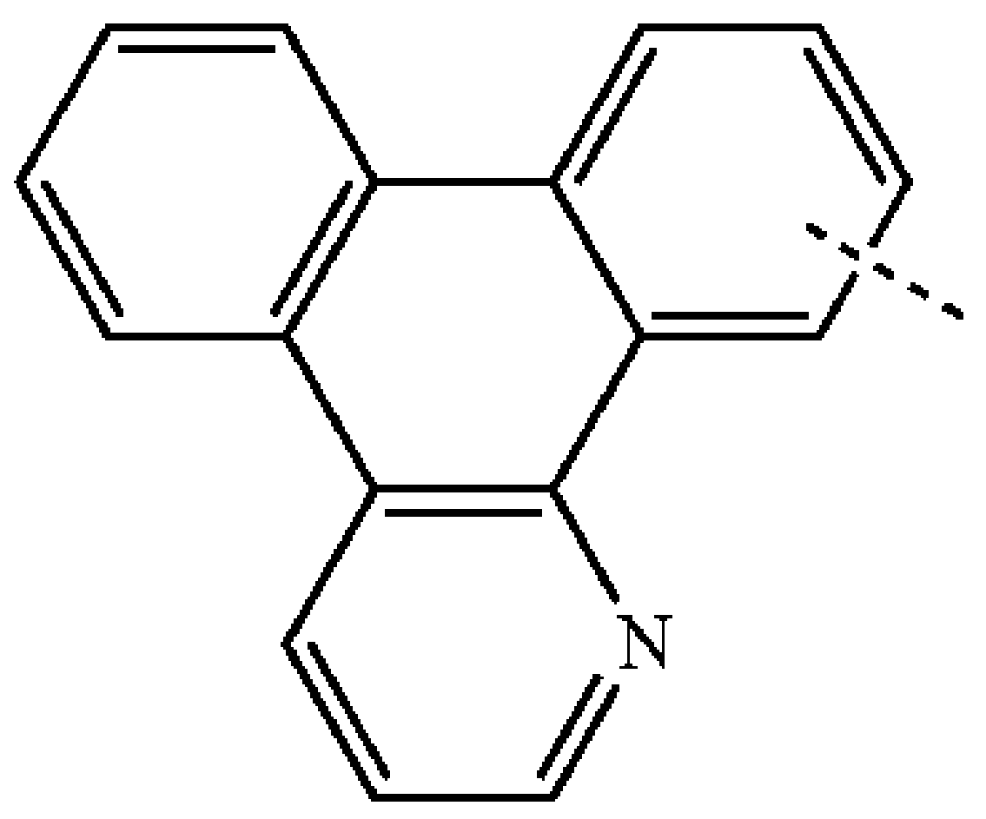
wherein X_1-X_{15} are independently selected from the group consisting of N and C—R", wherein R" is selected from a group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein Y_1 and Y_2 are independently selected from the group consisting of O, S, and Se.

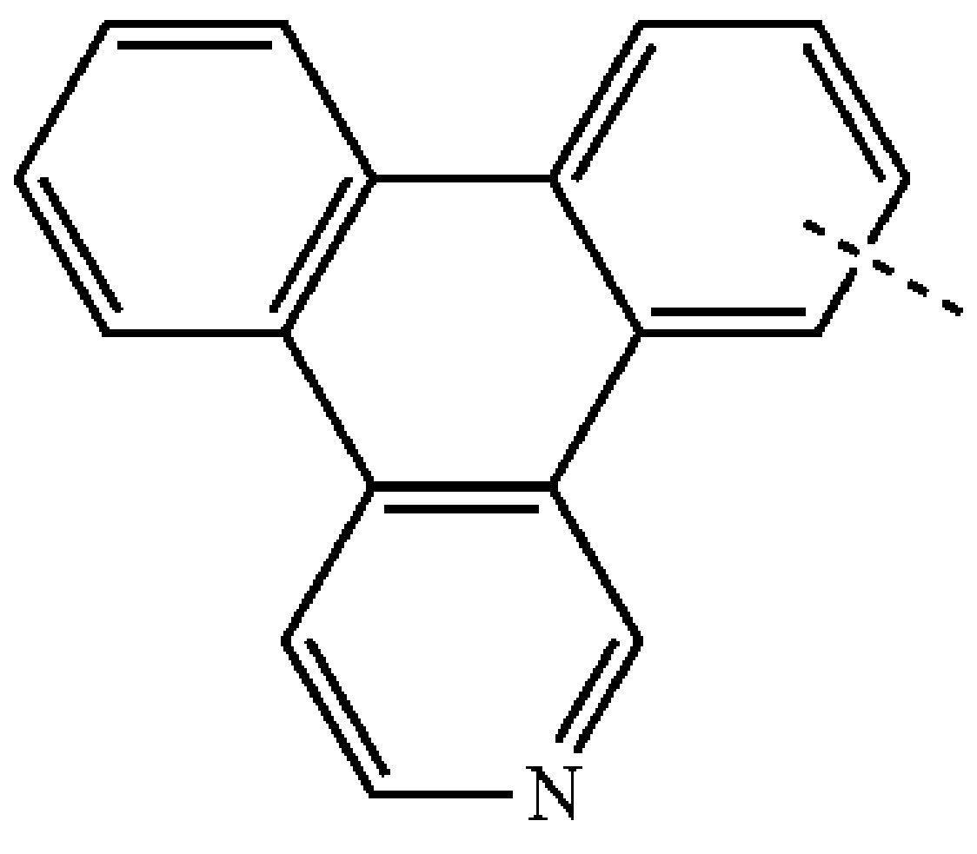
In one aspect, A is selected from the group consisting of:

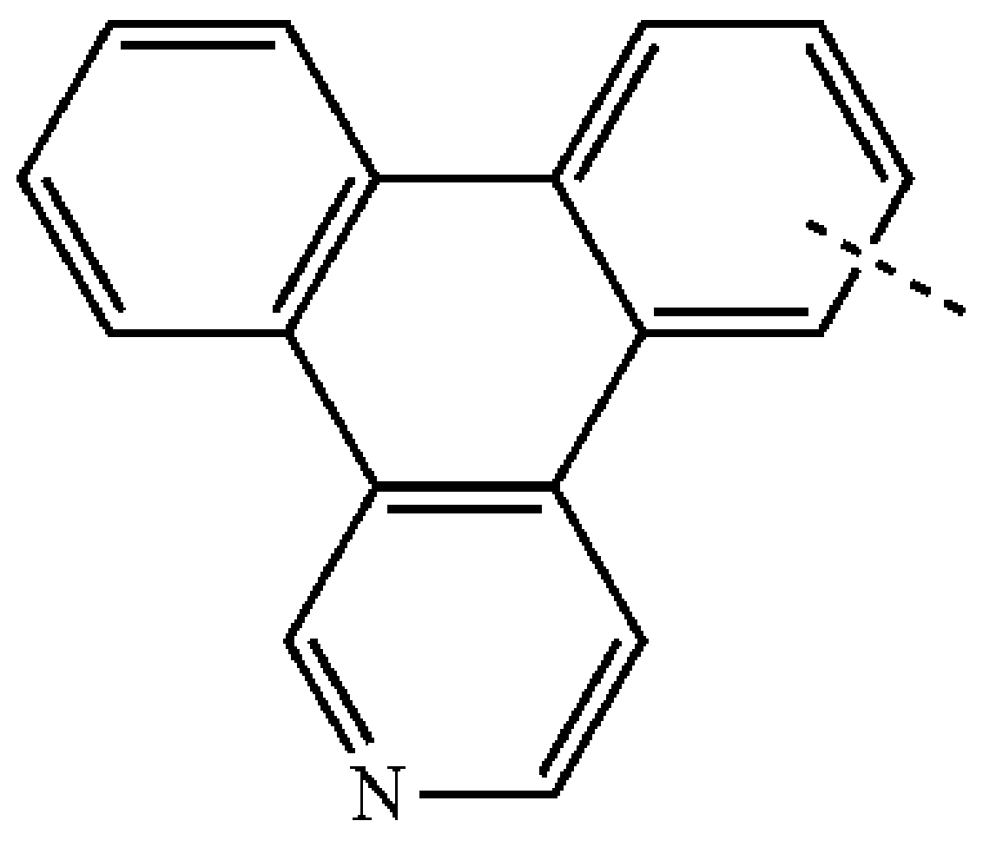


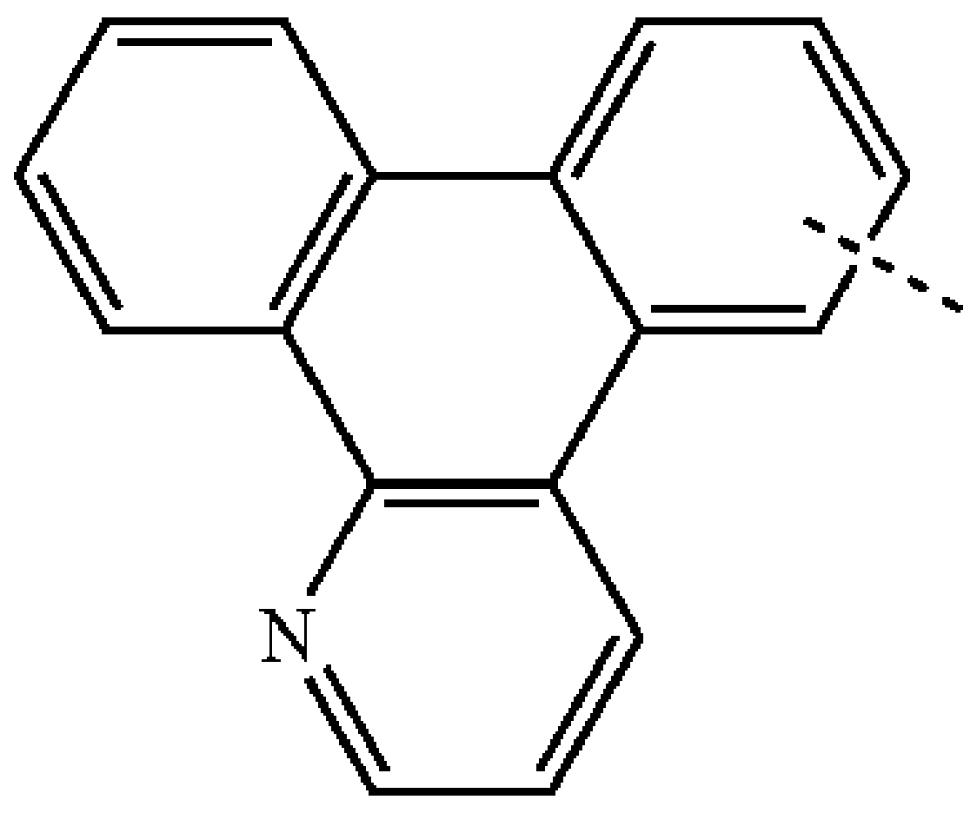


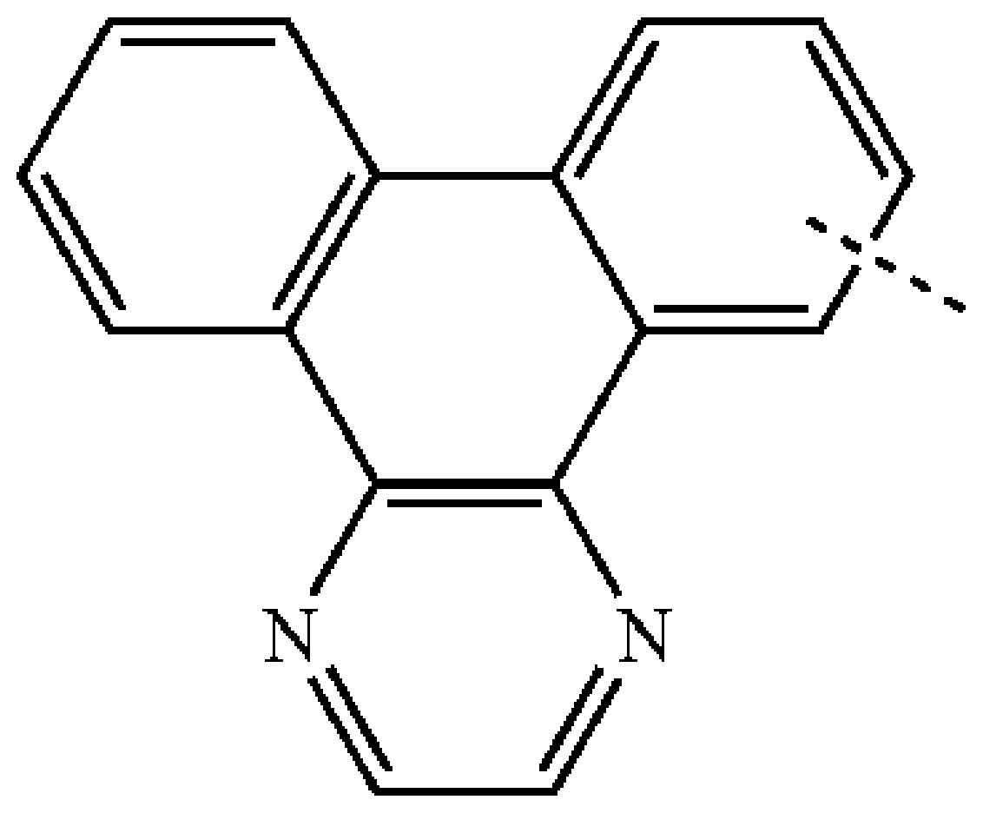


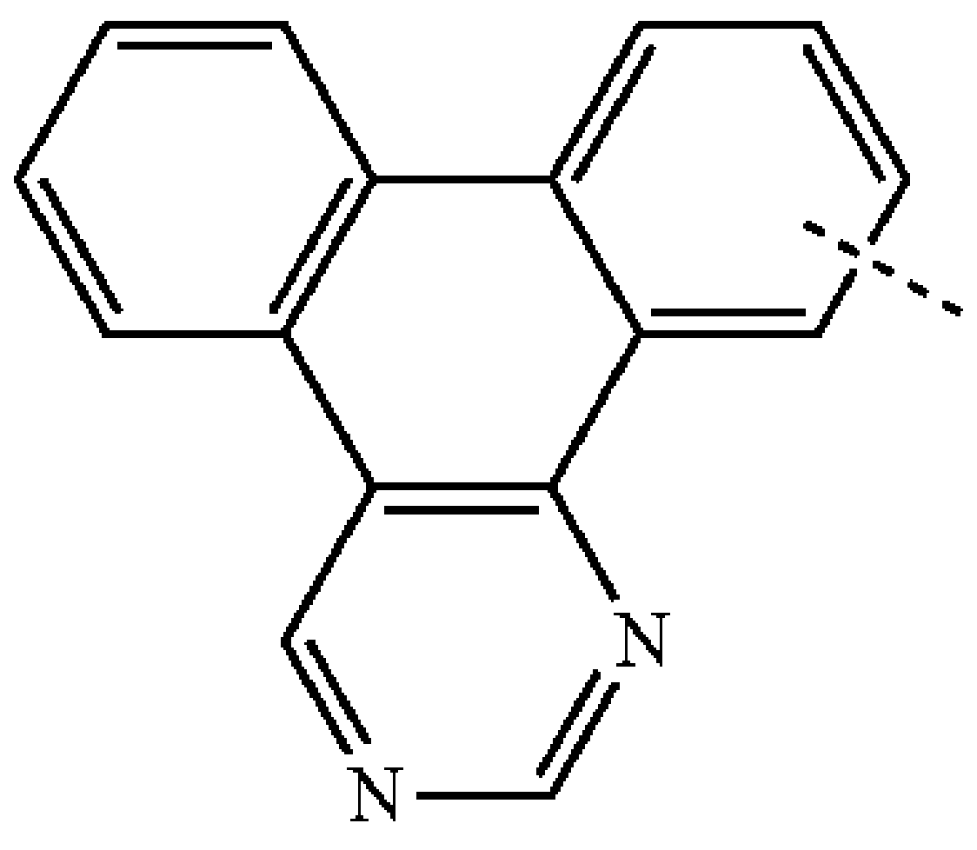


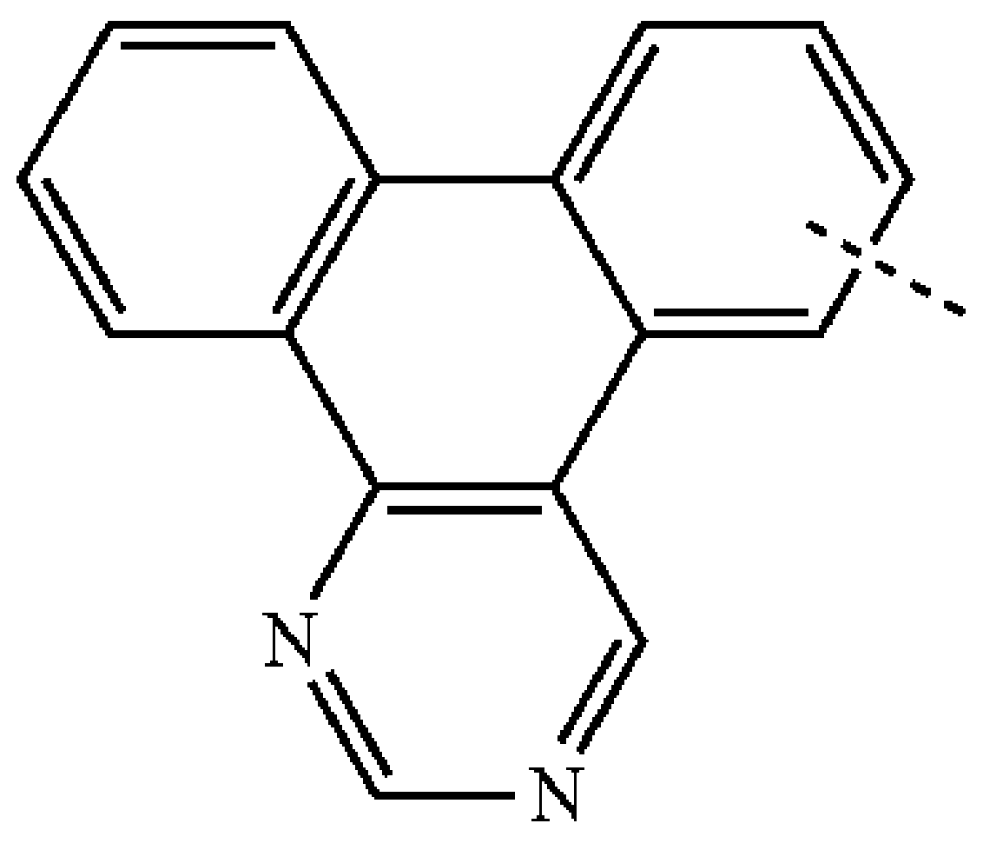












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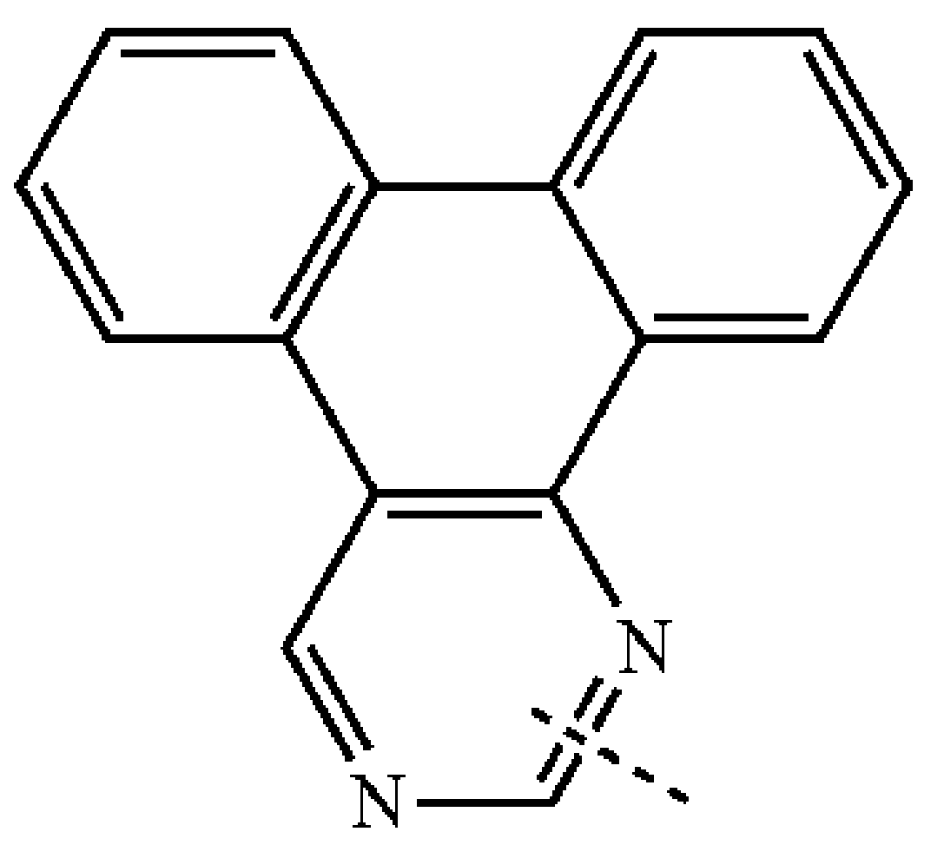

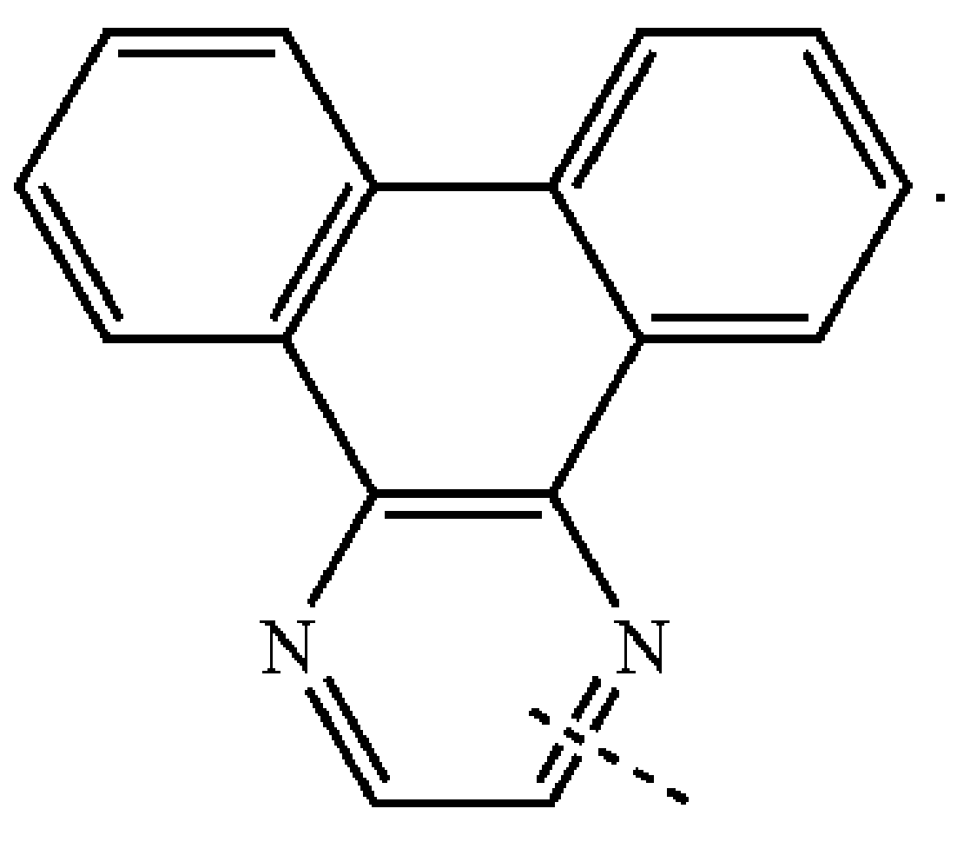

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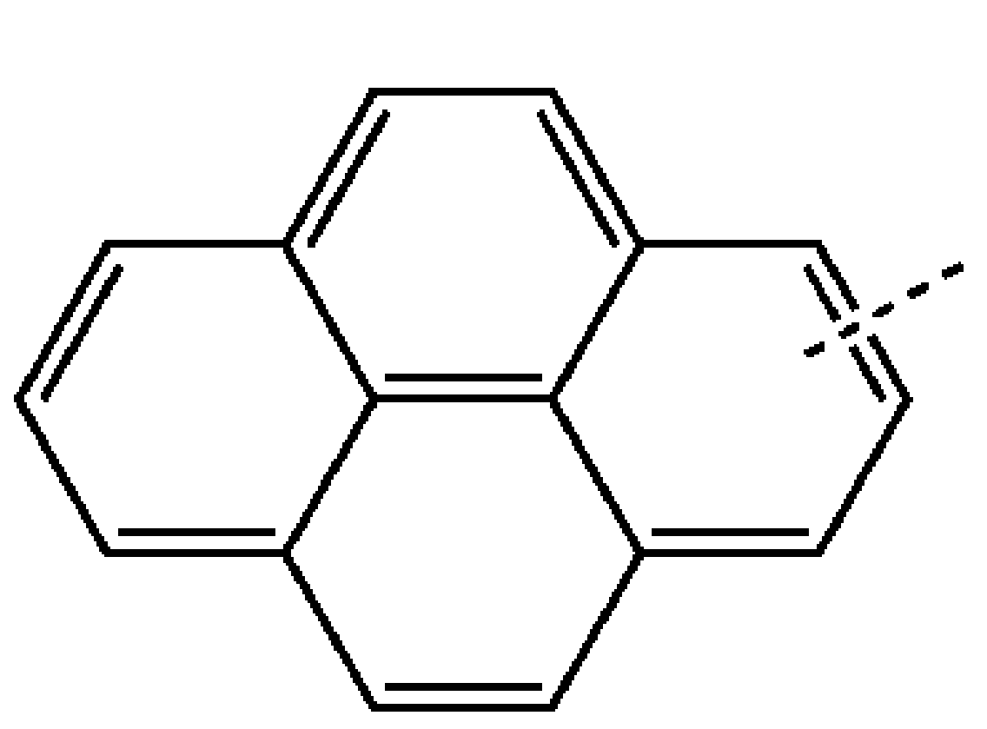

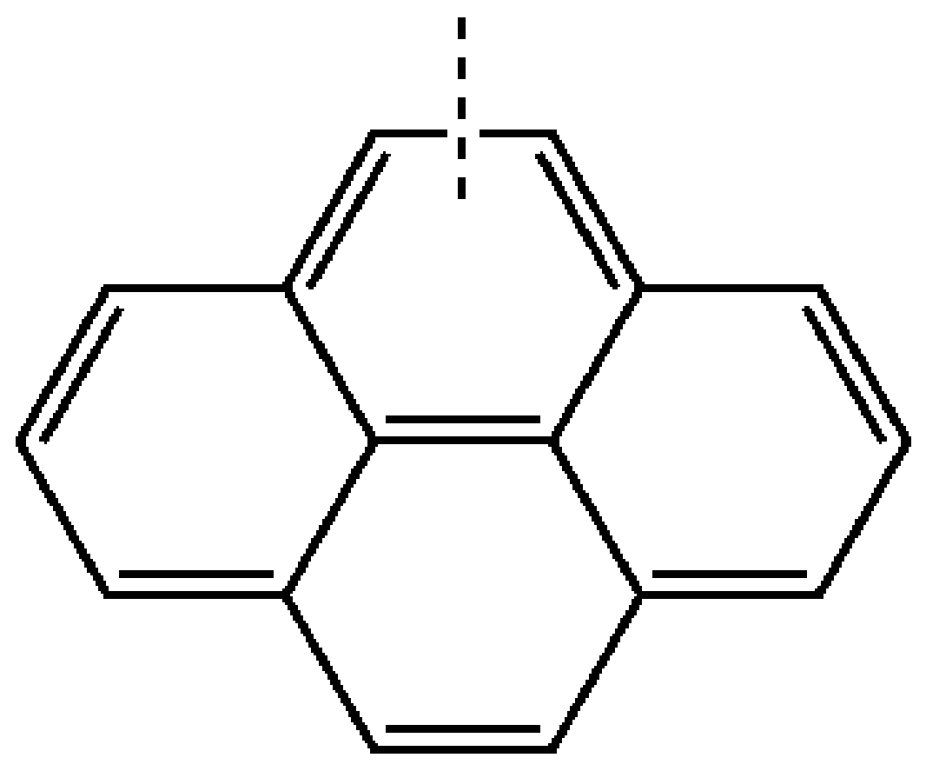

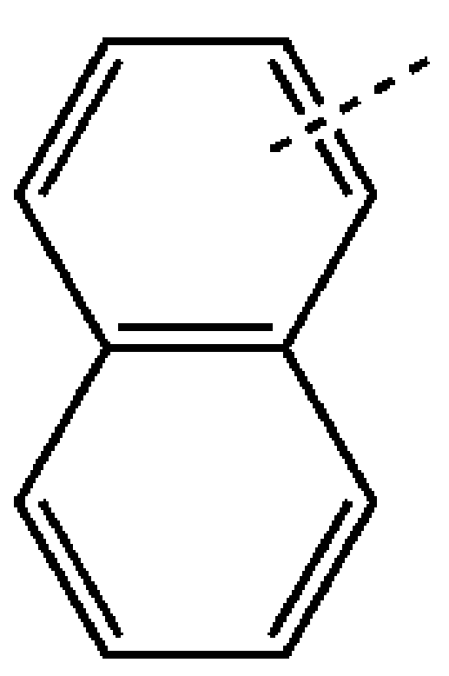

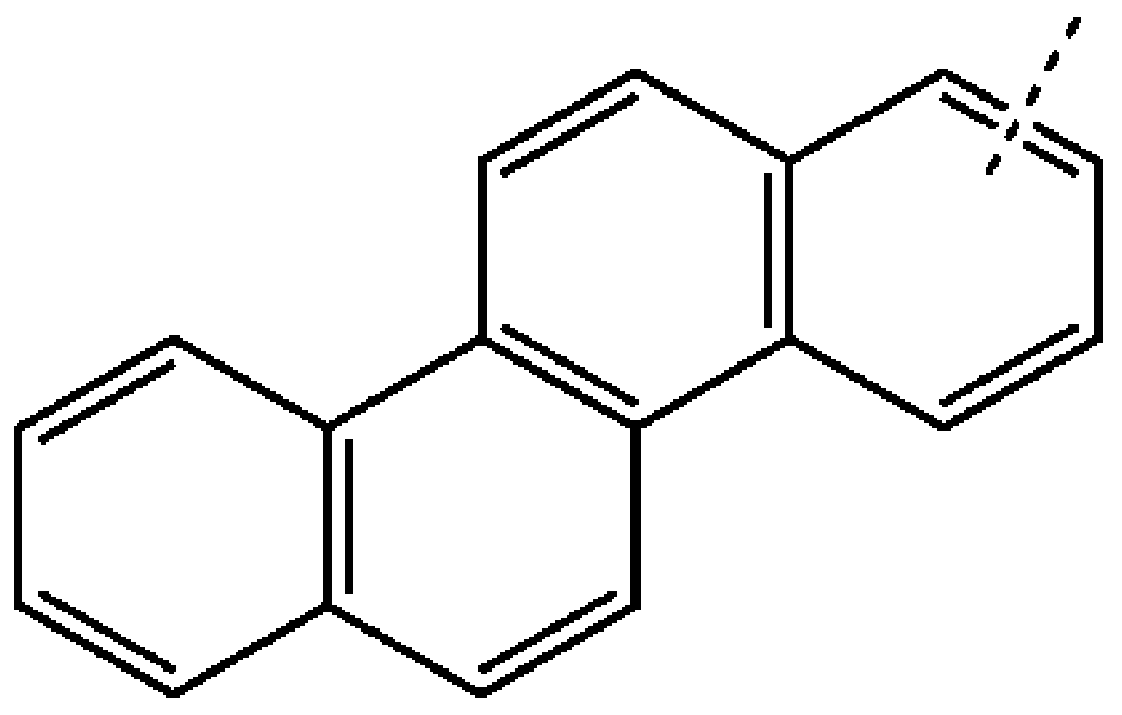

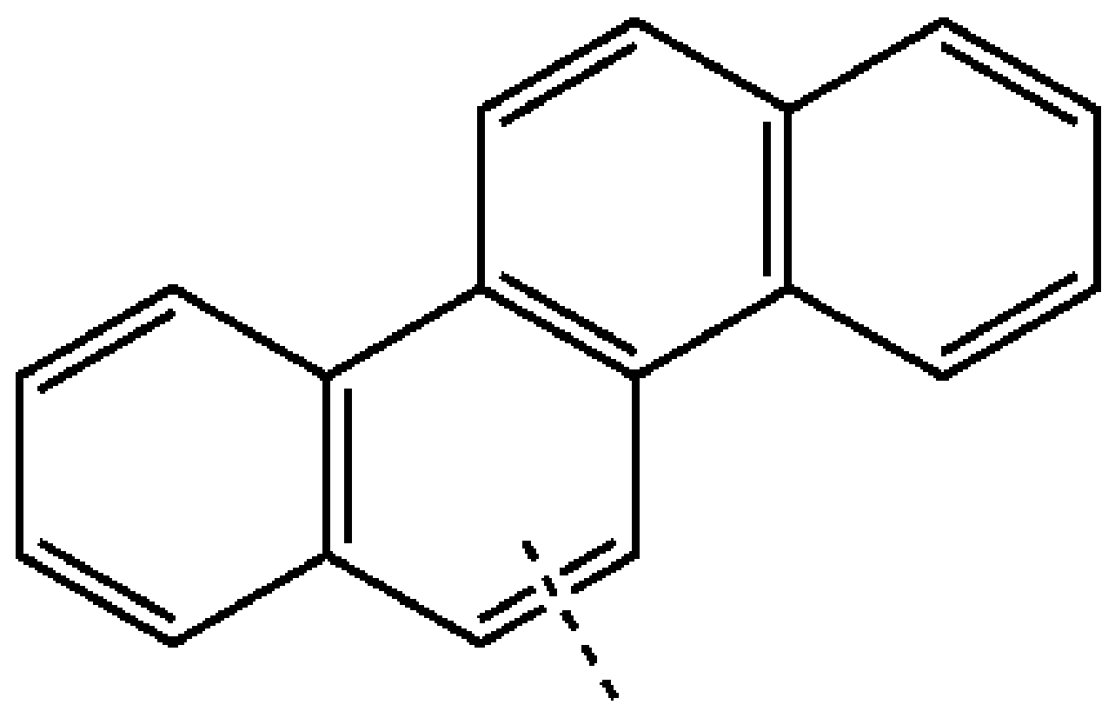

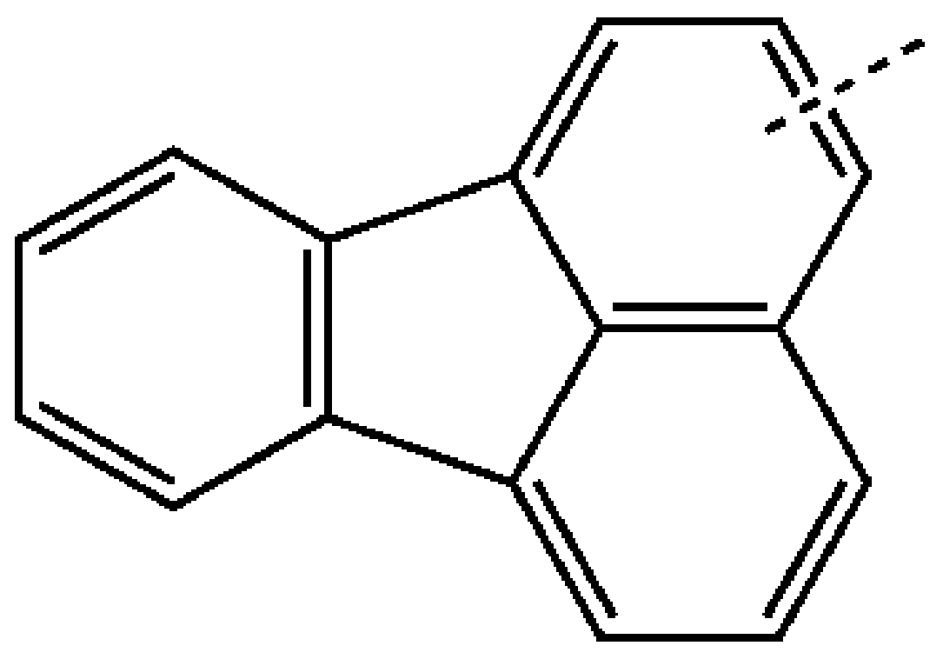

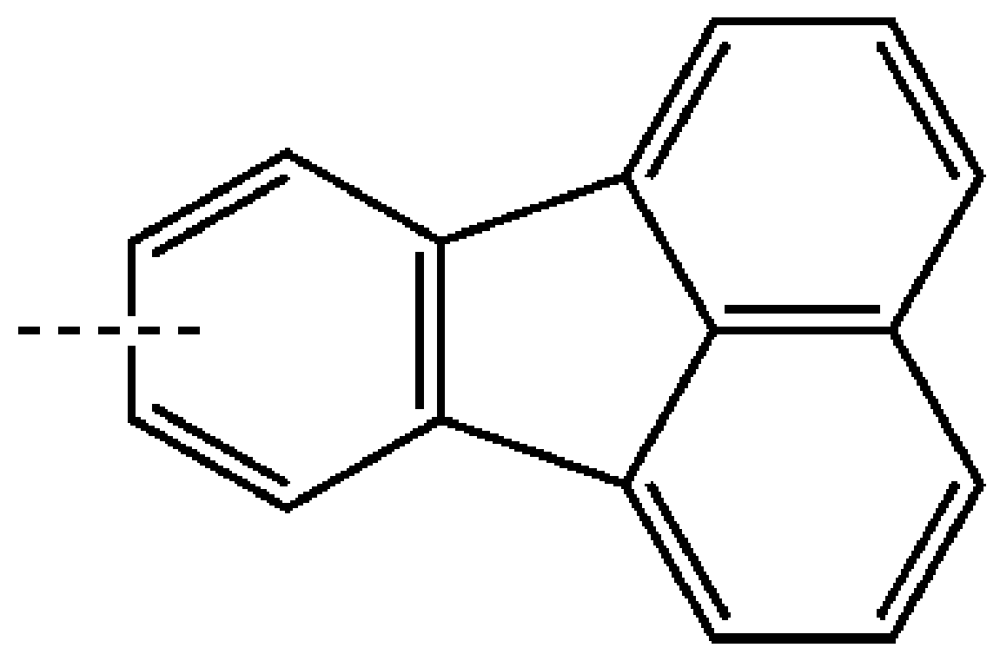

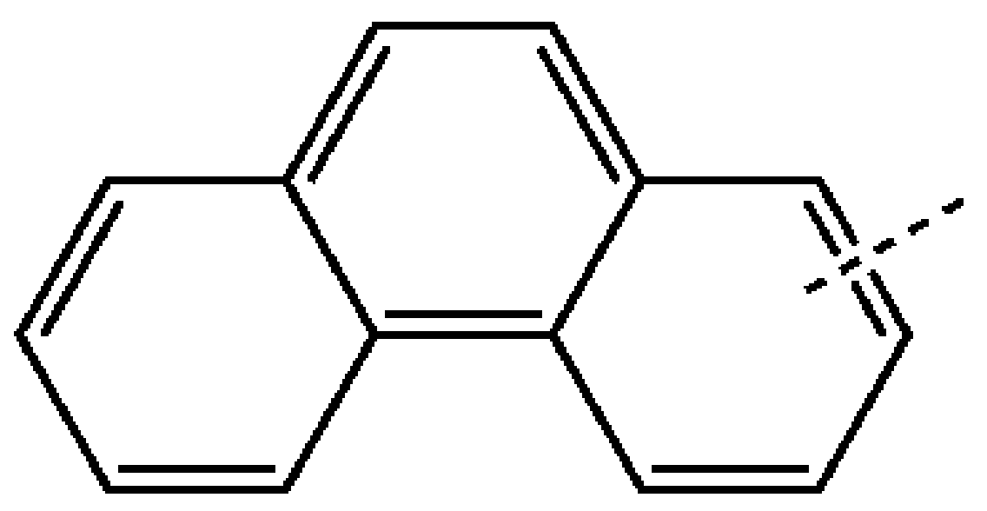

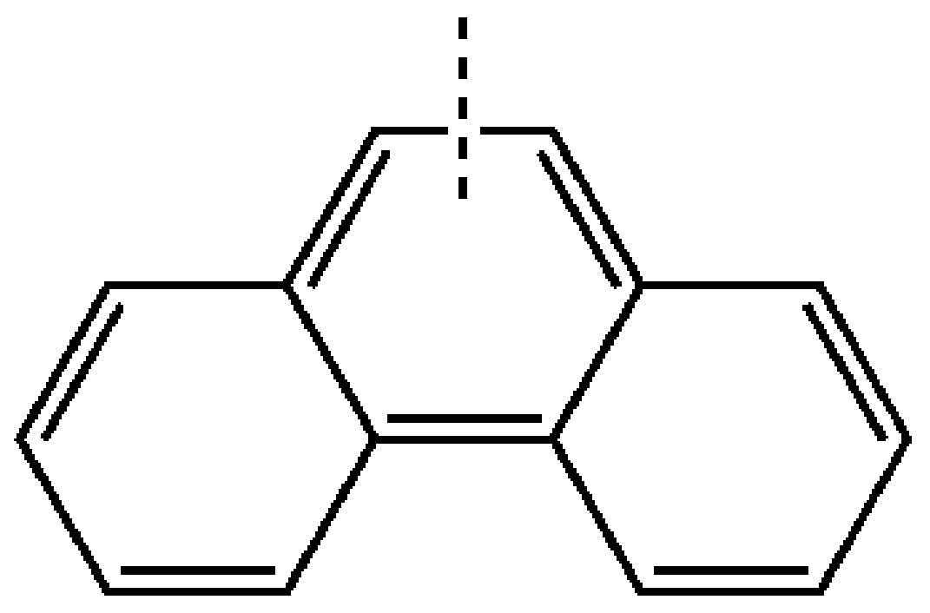

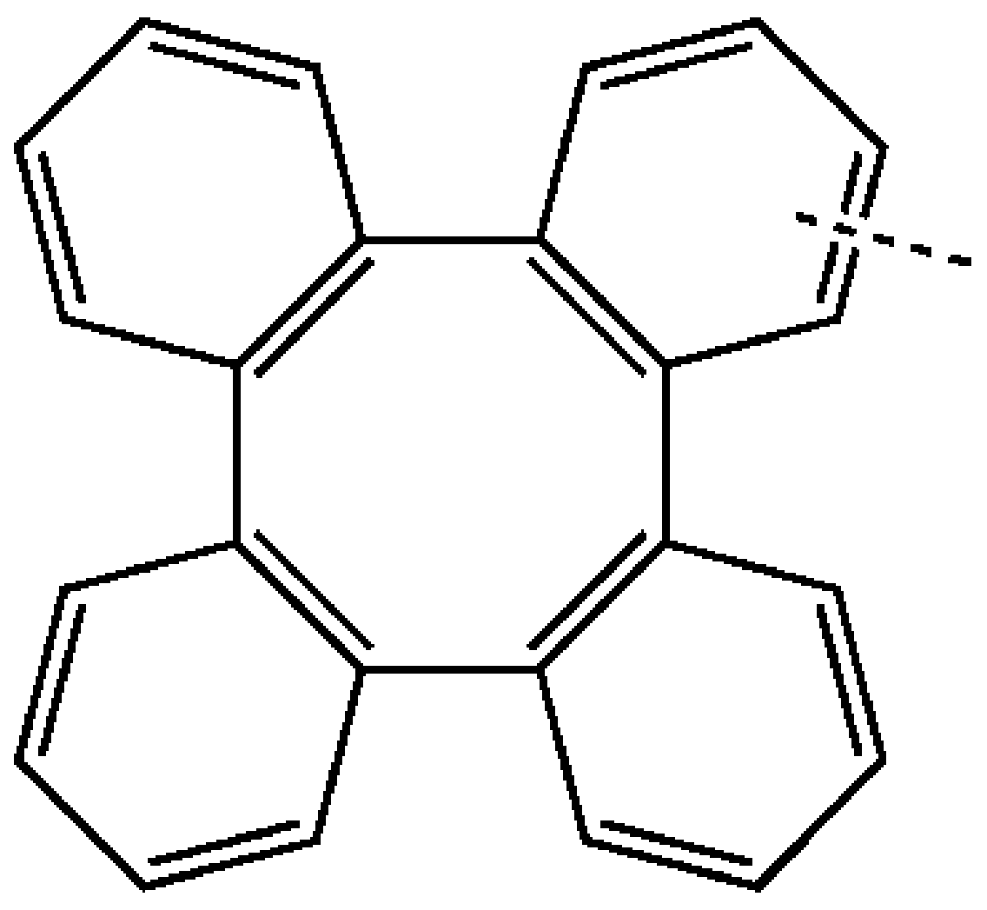

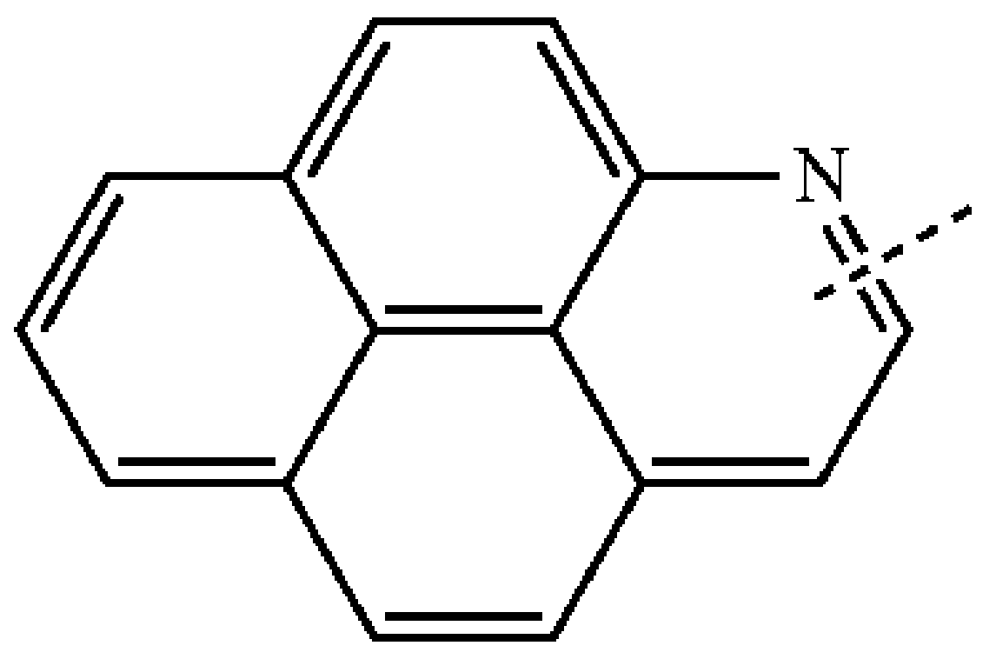

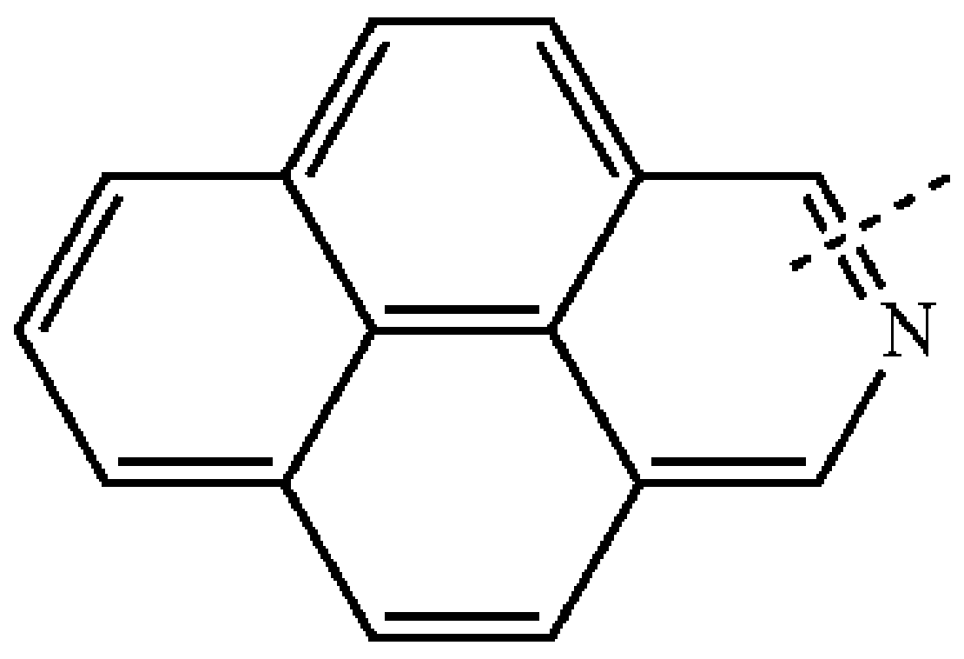

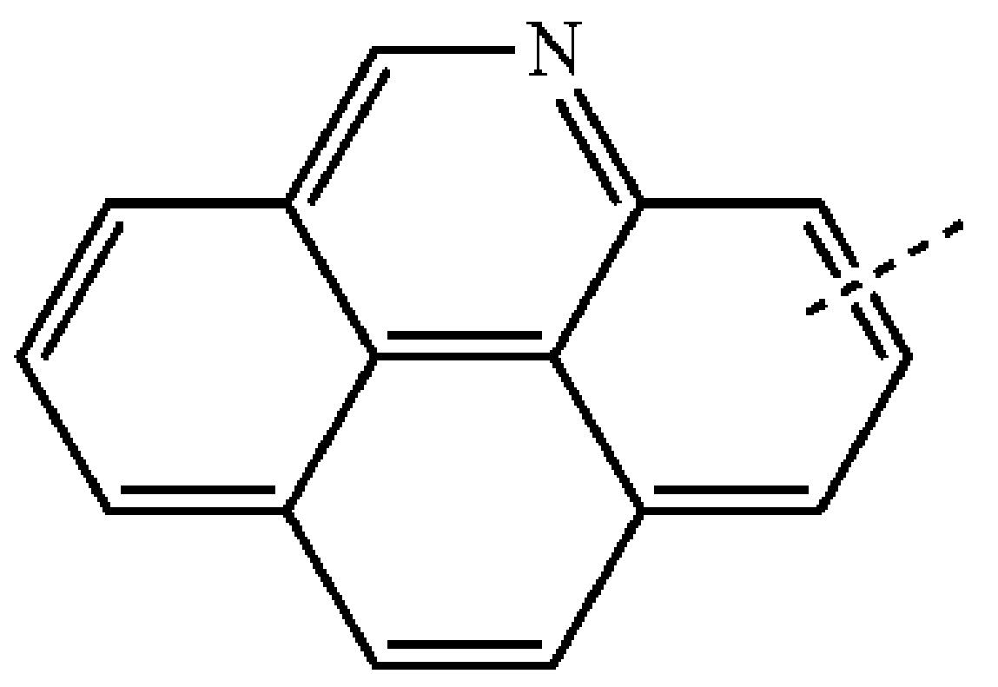

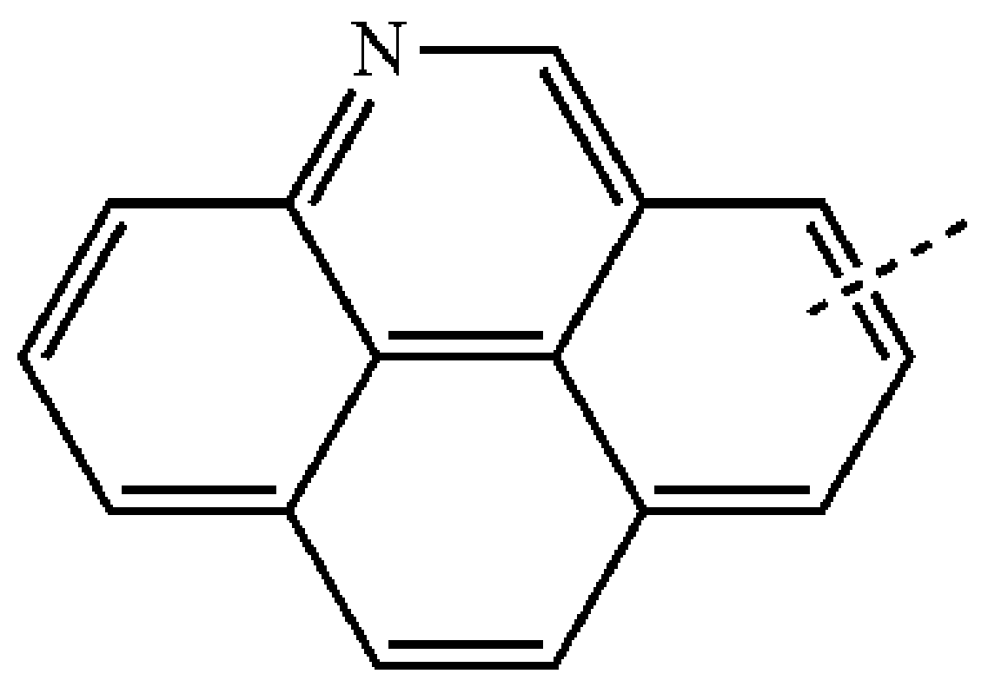

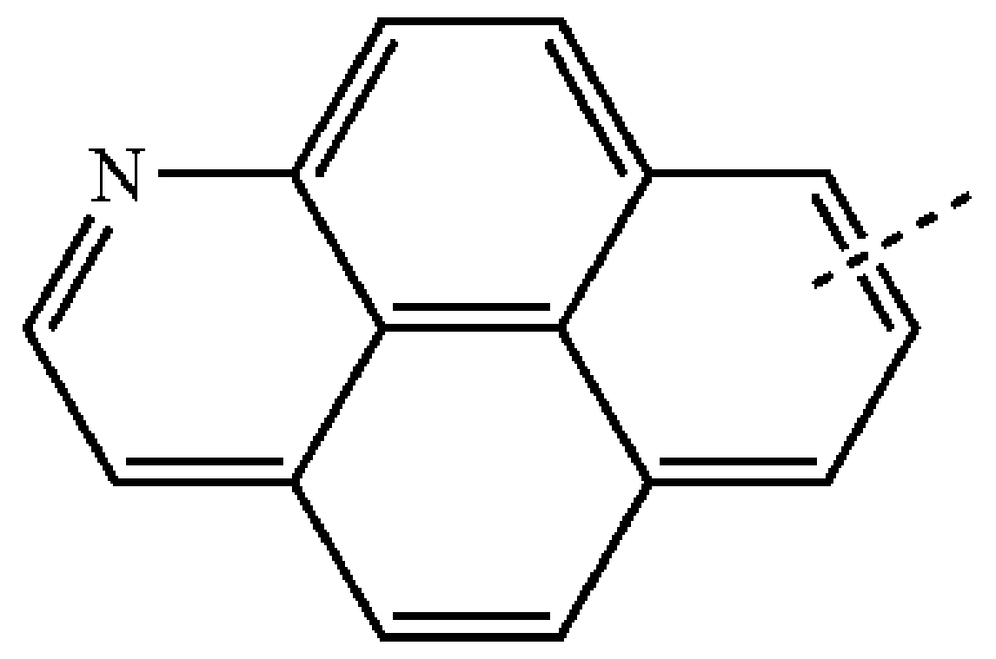

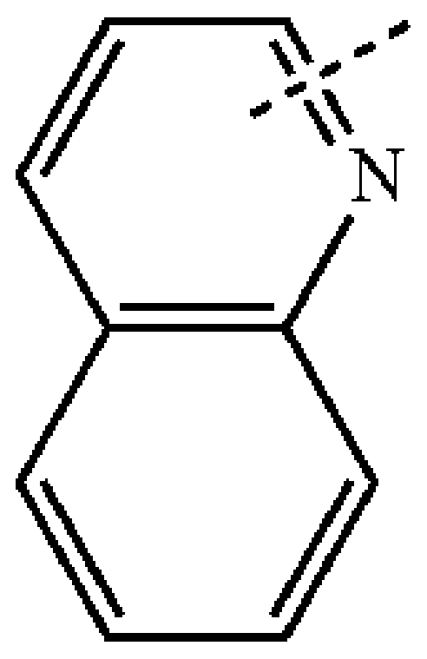

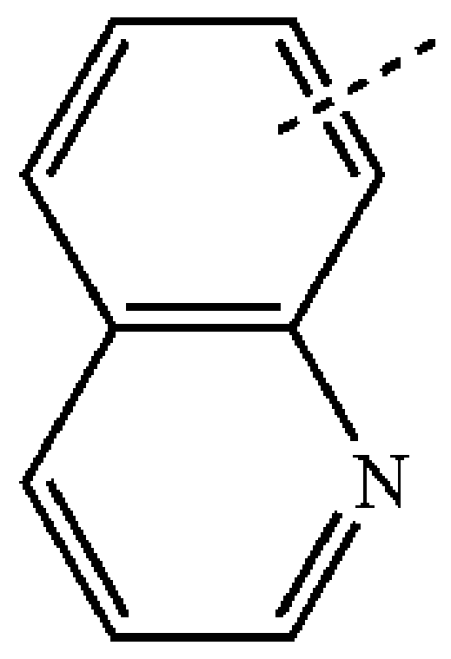

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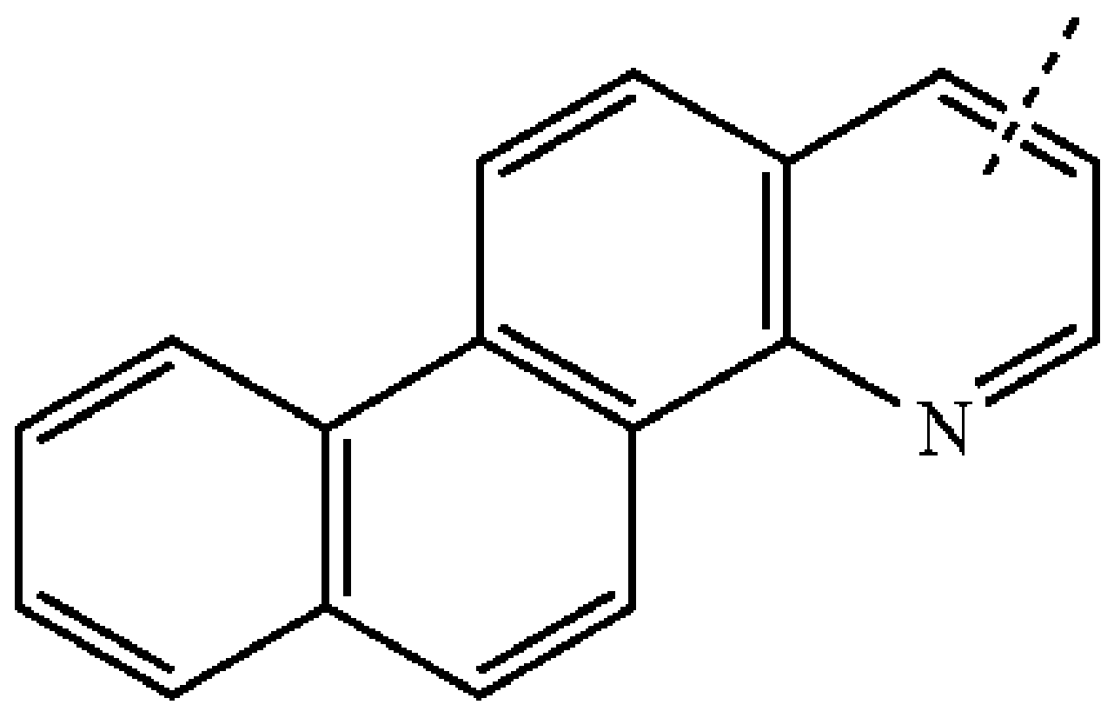

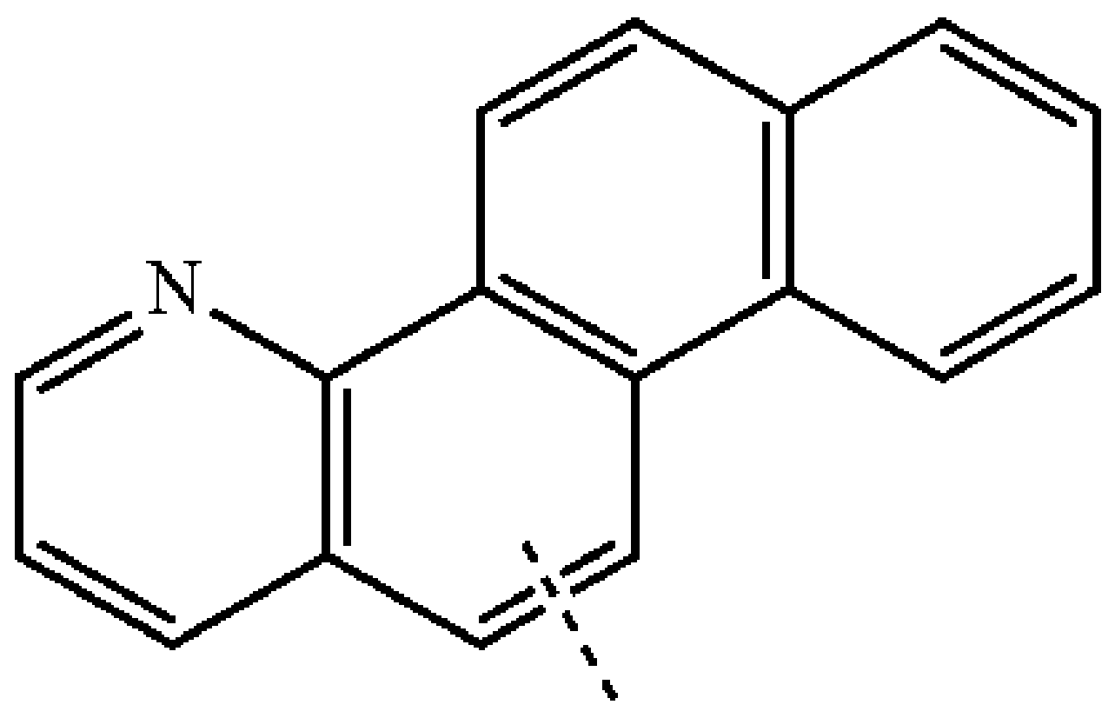

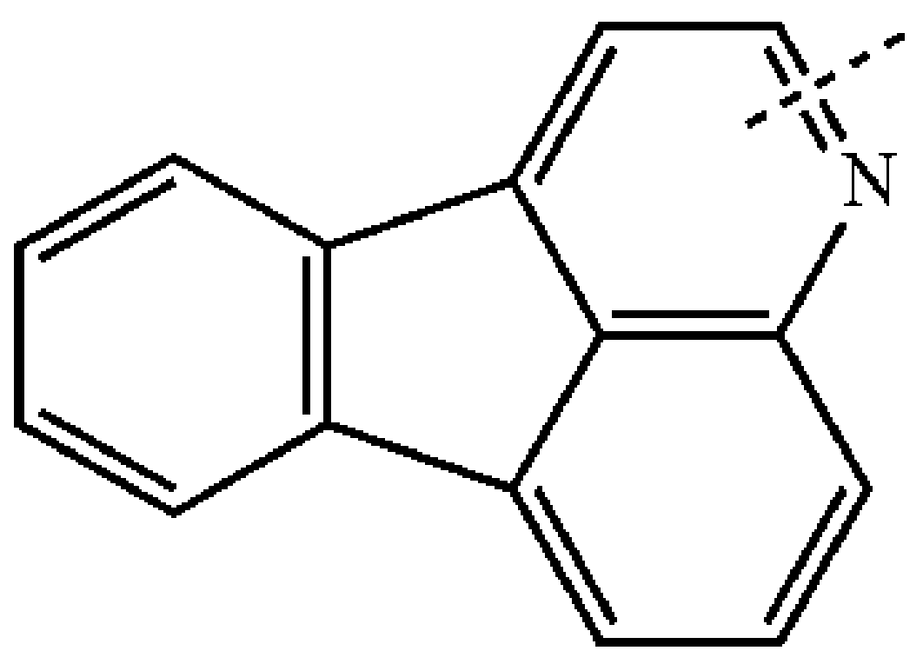

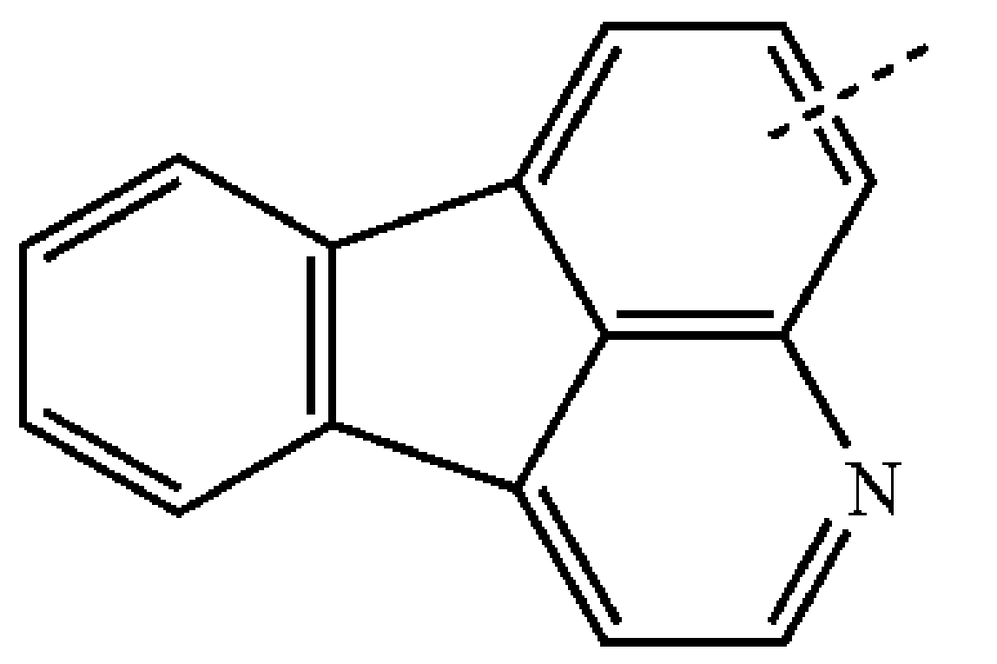

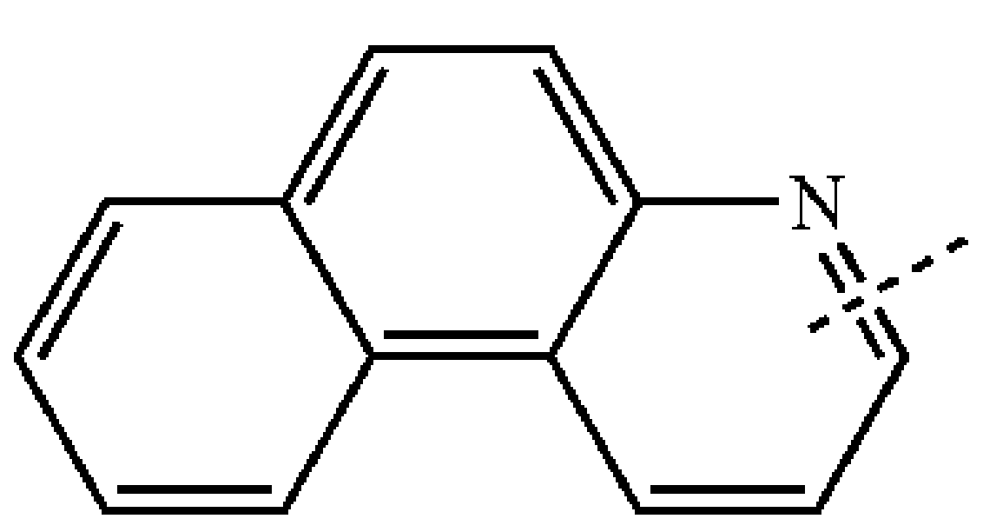

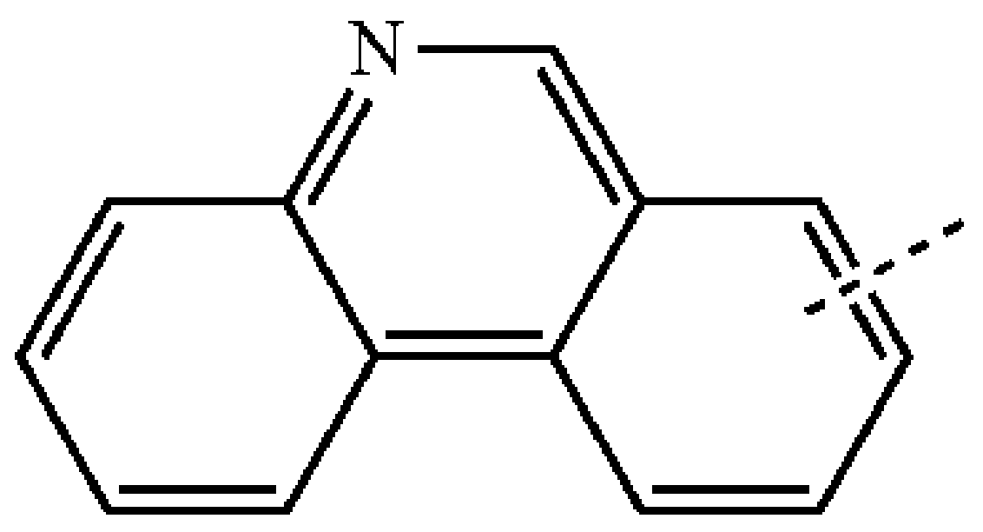

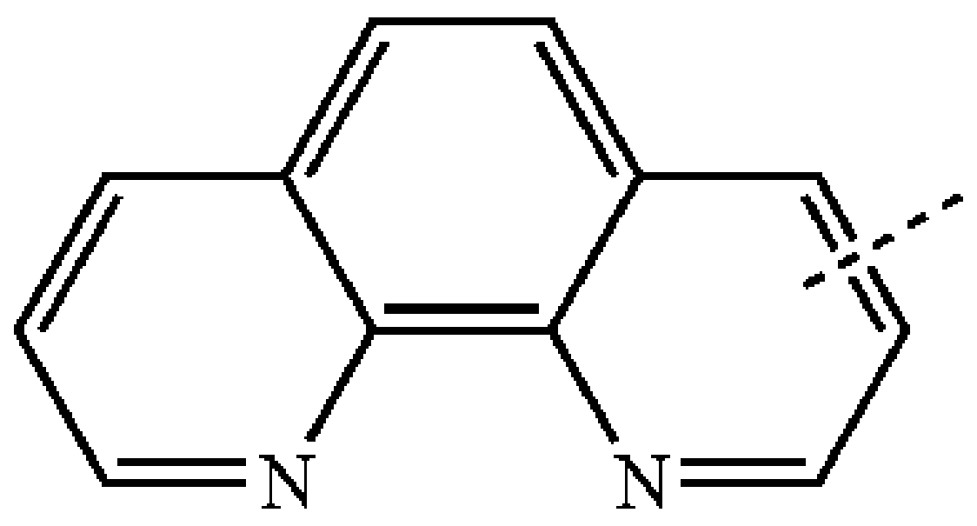

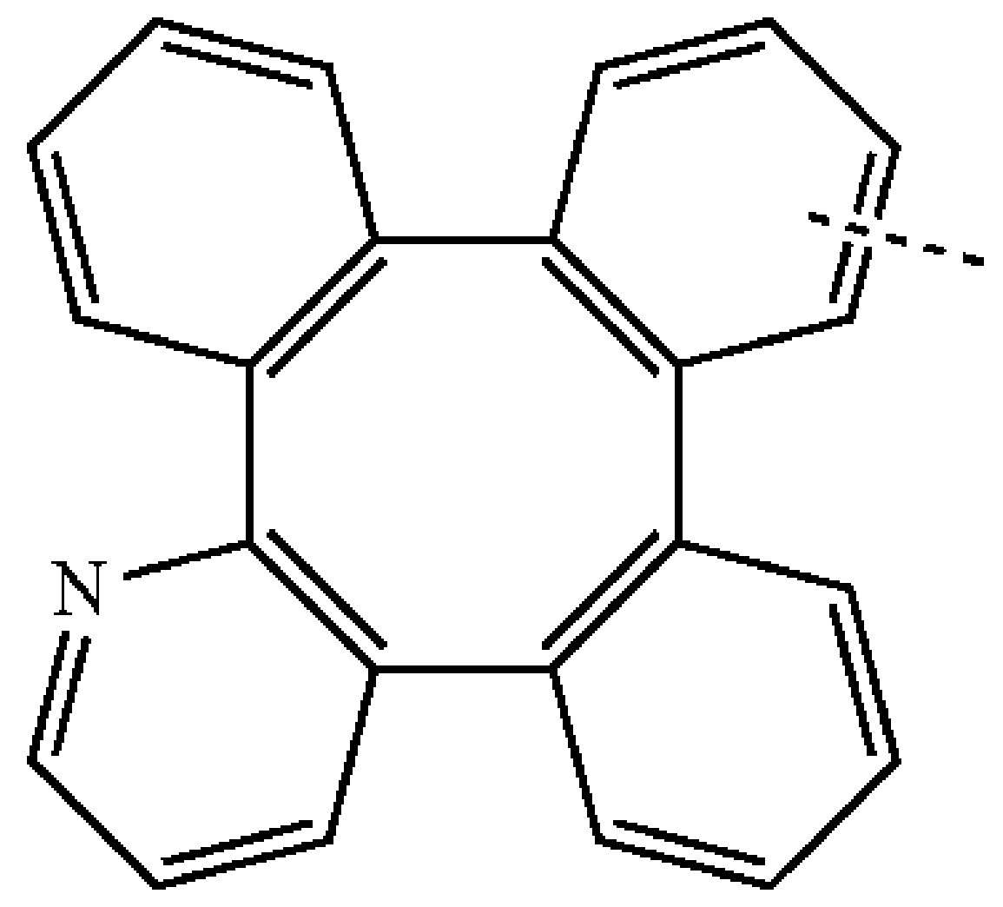

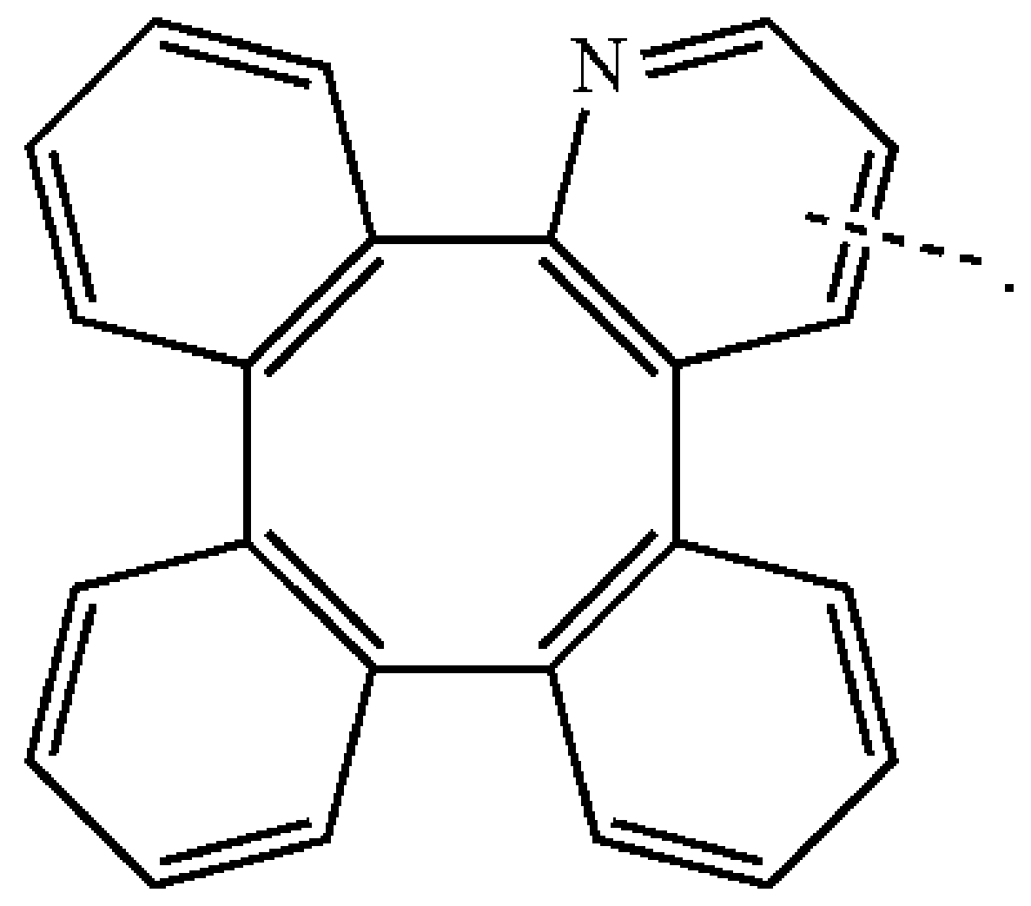

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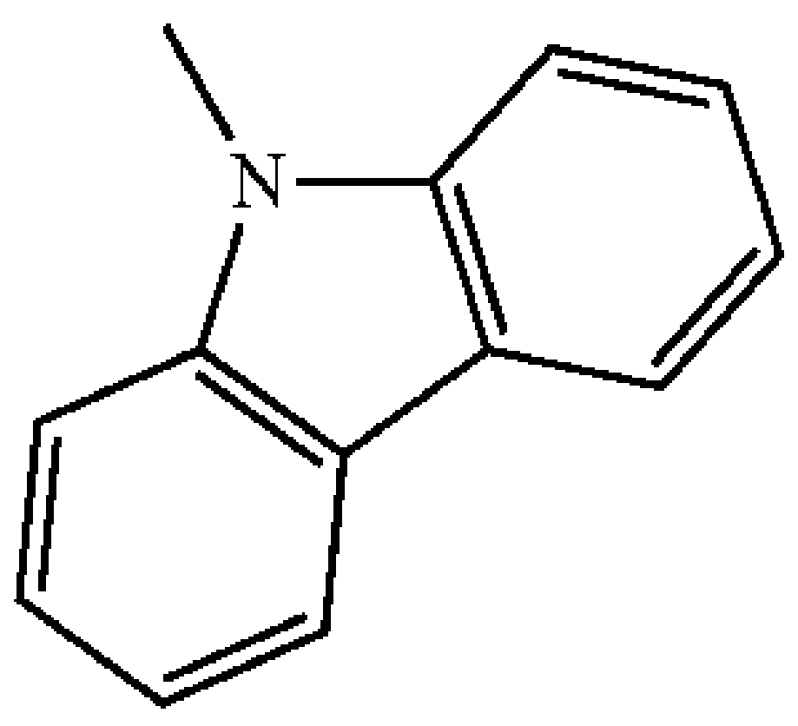

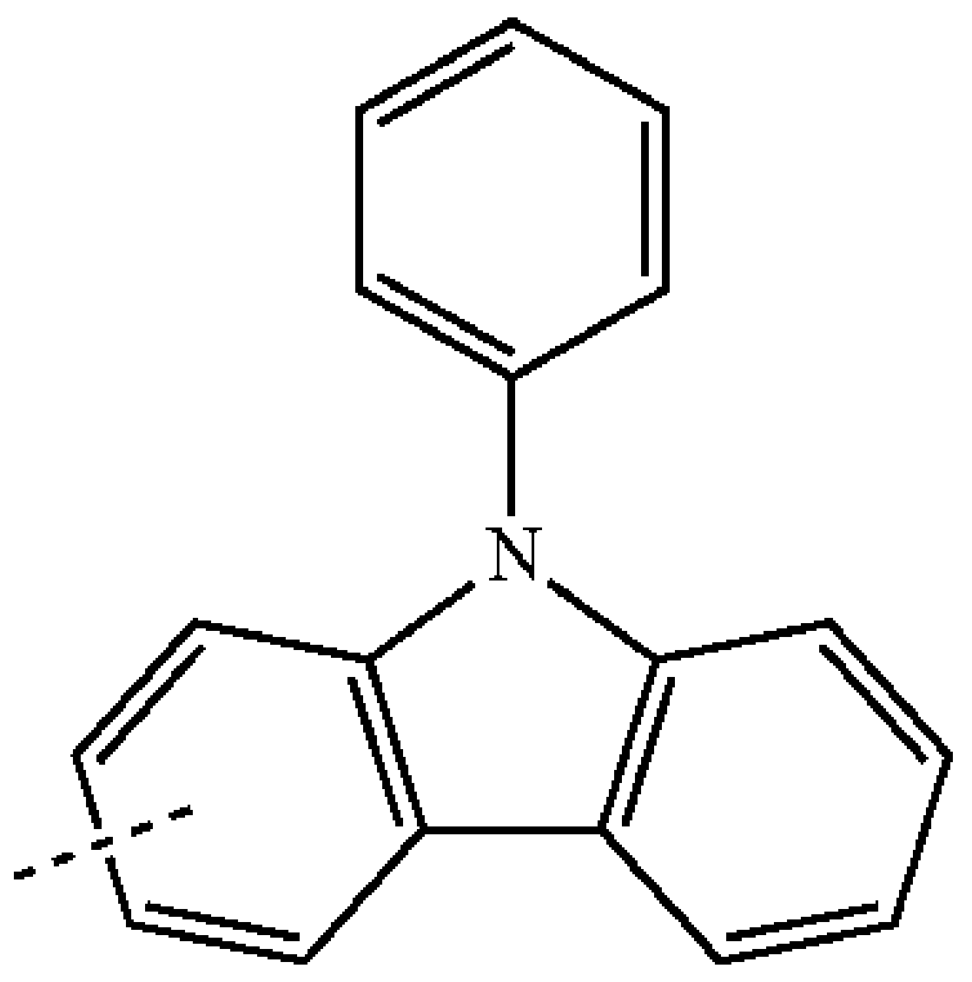

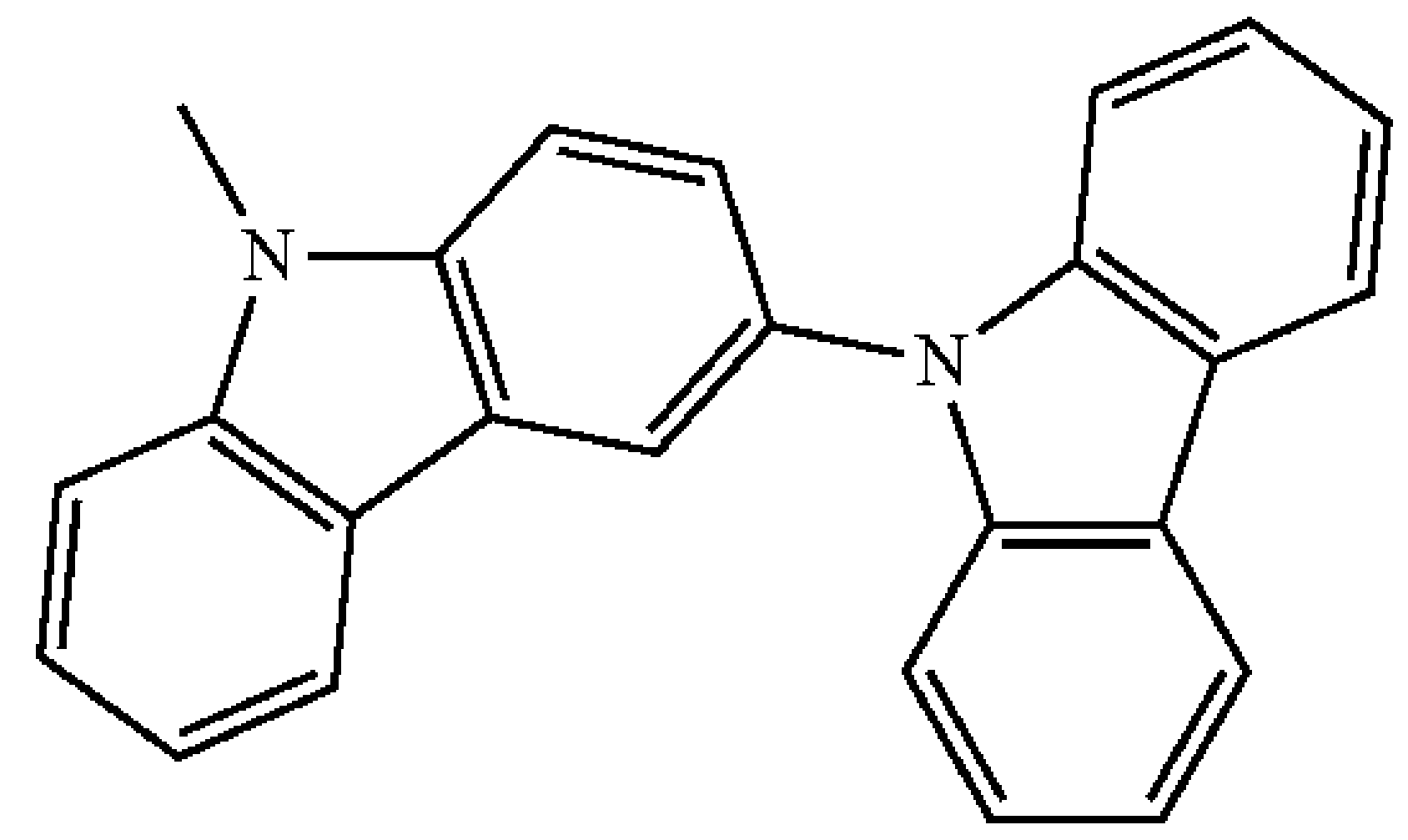

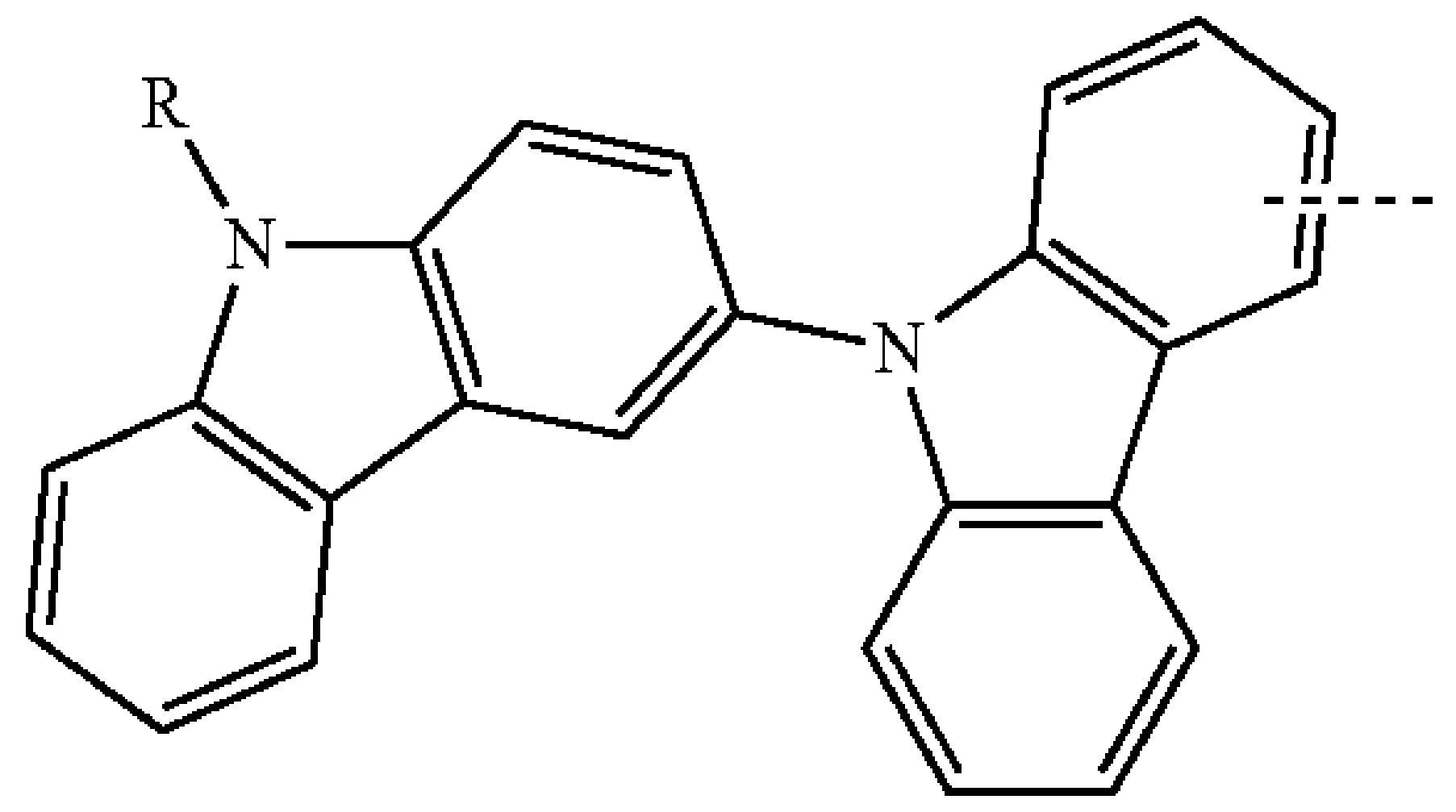

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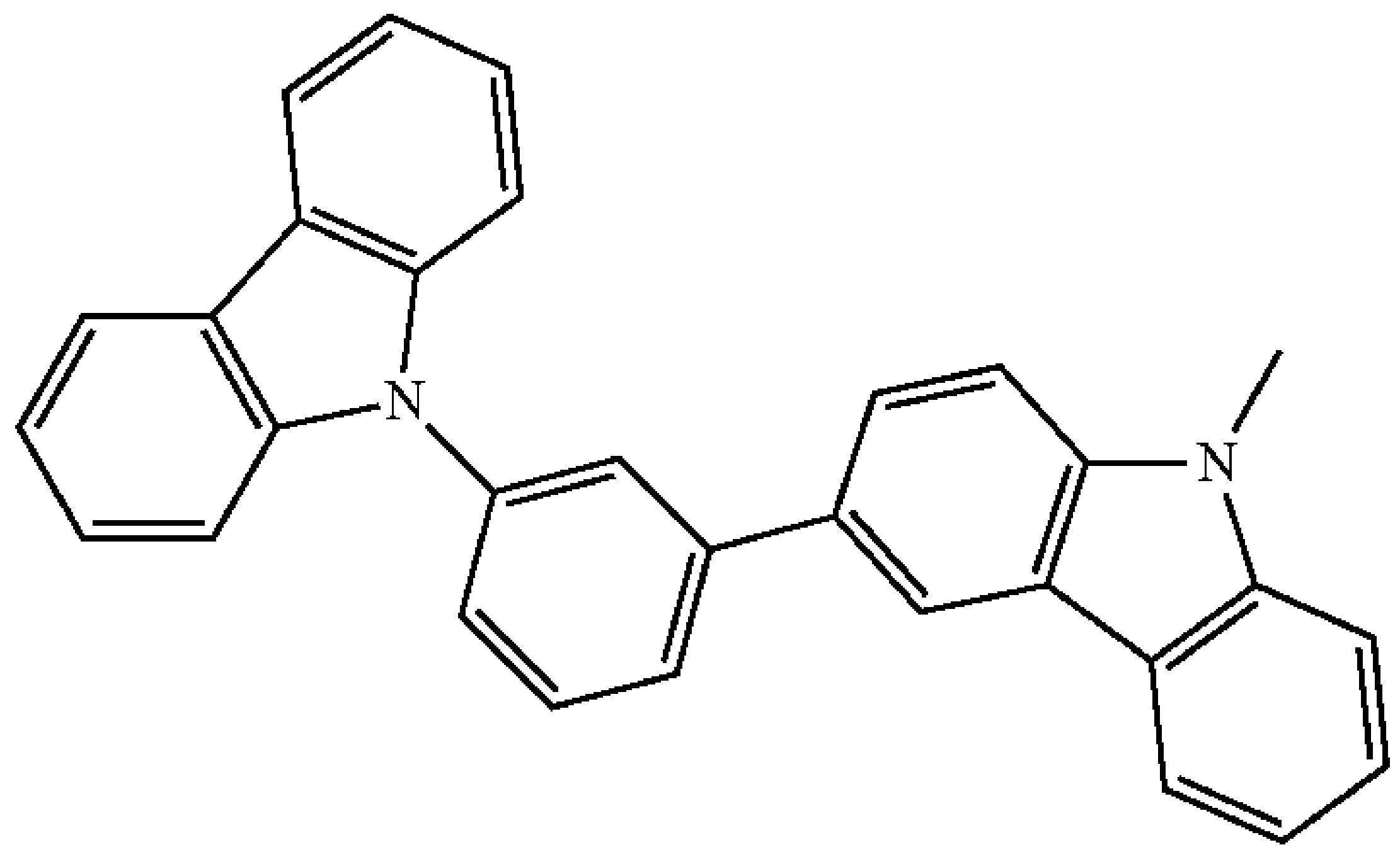

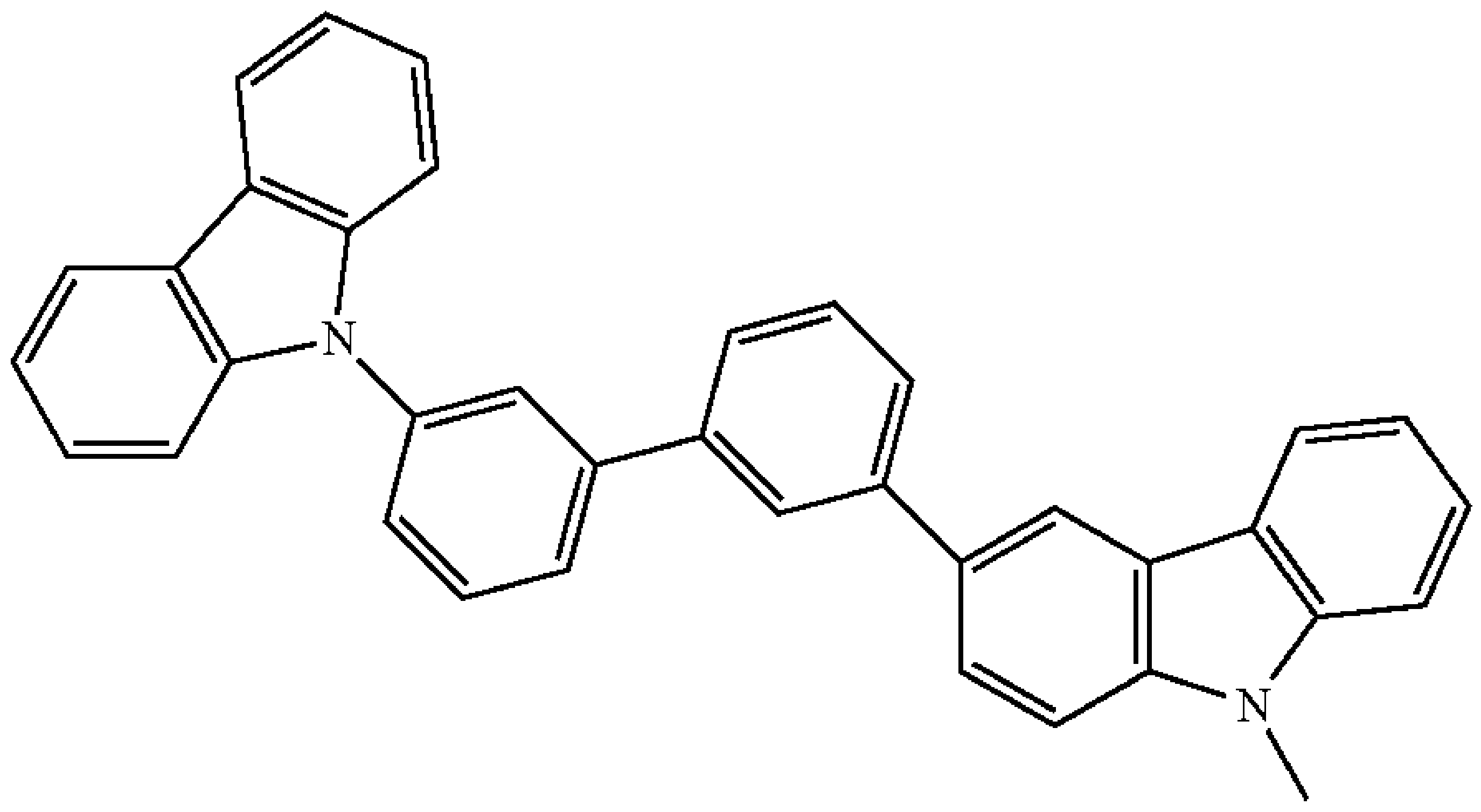

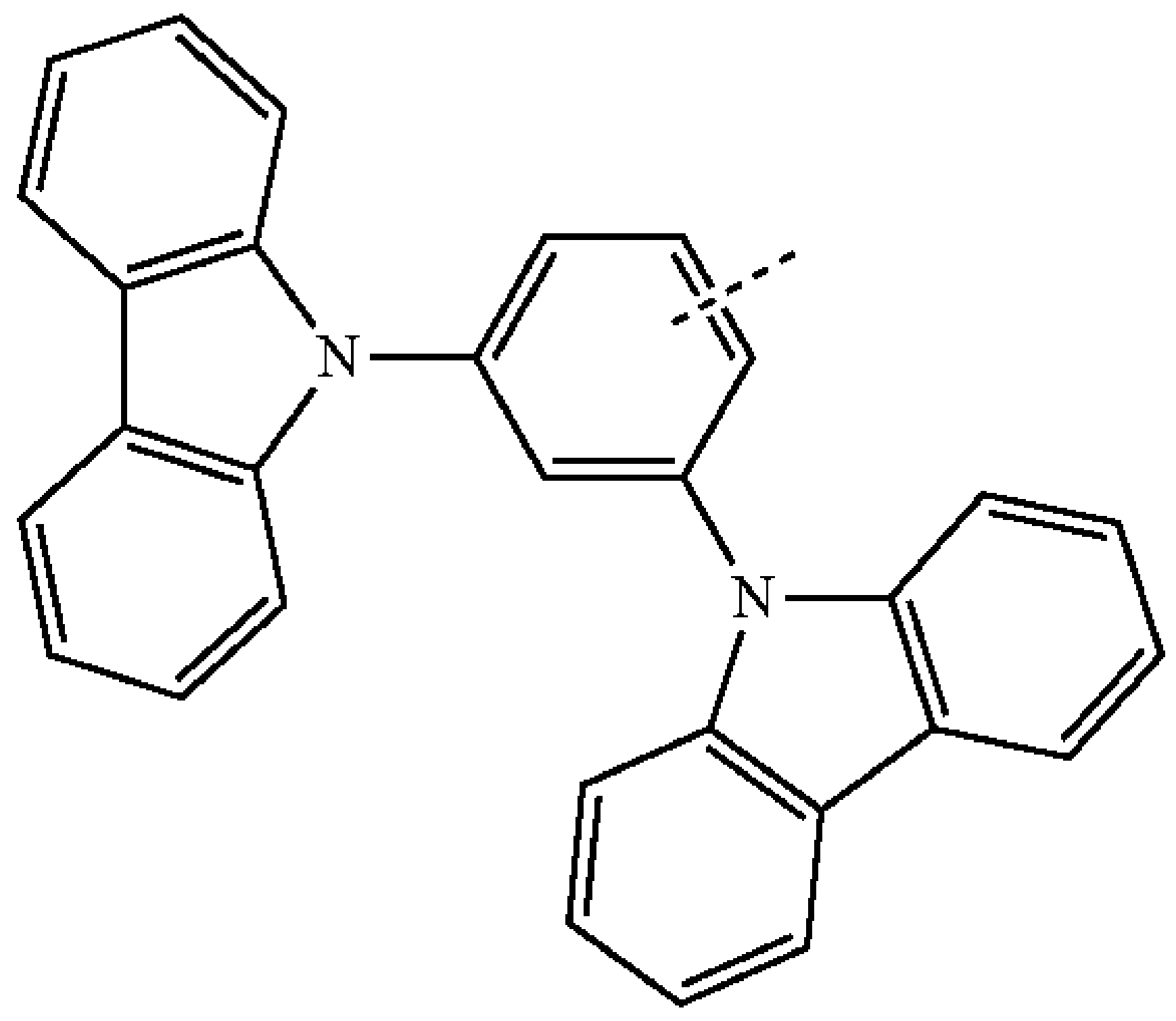

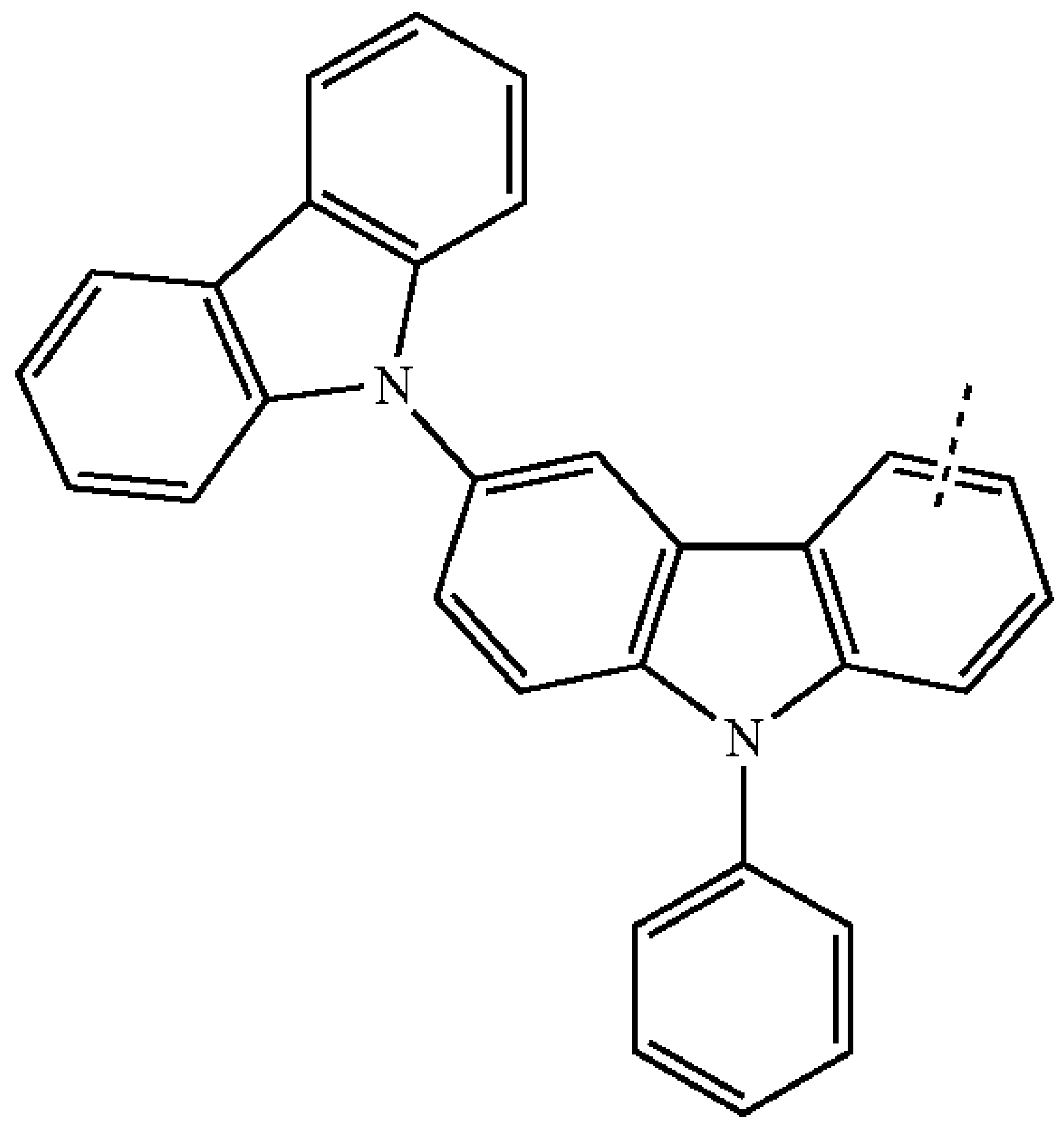

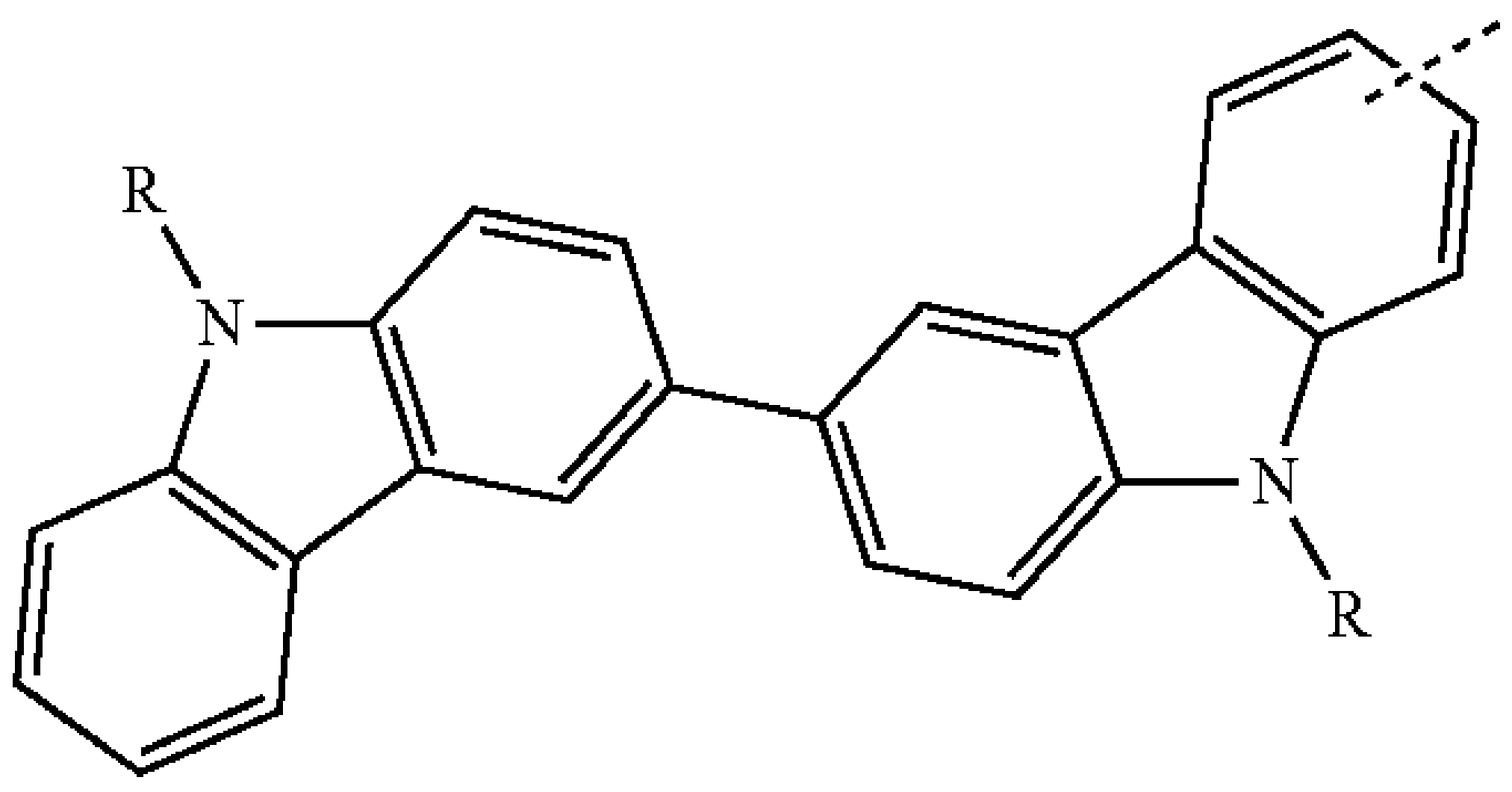

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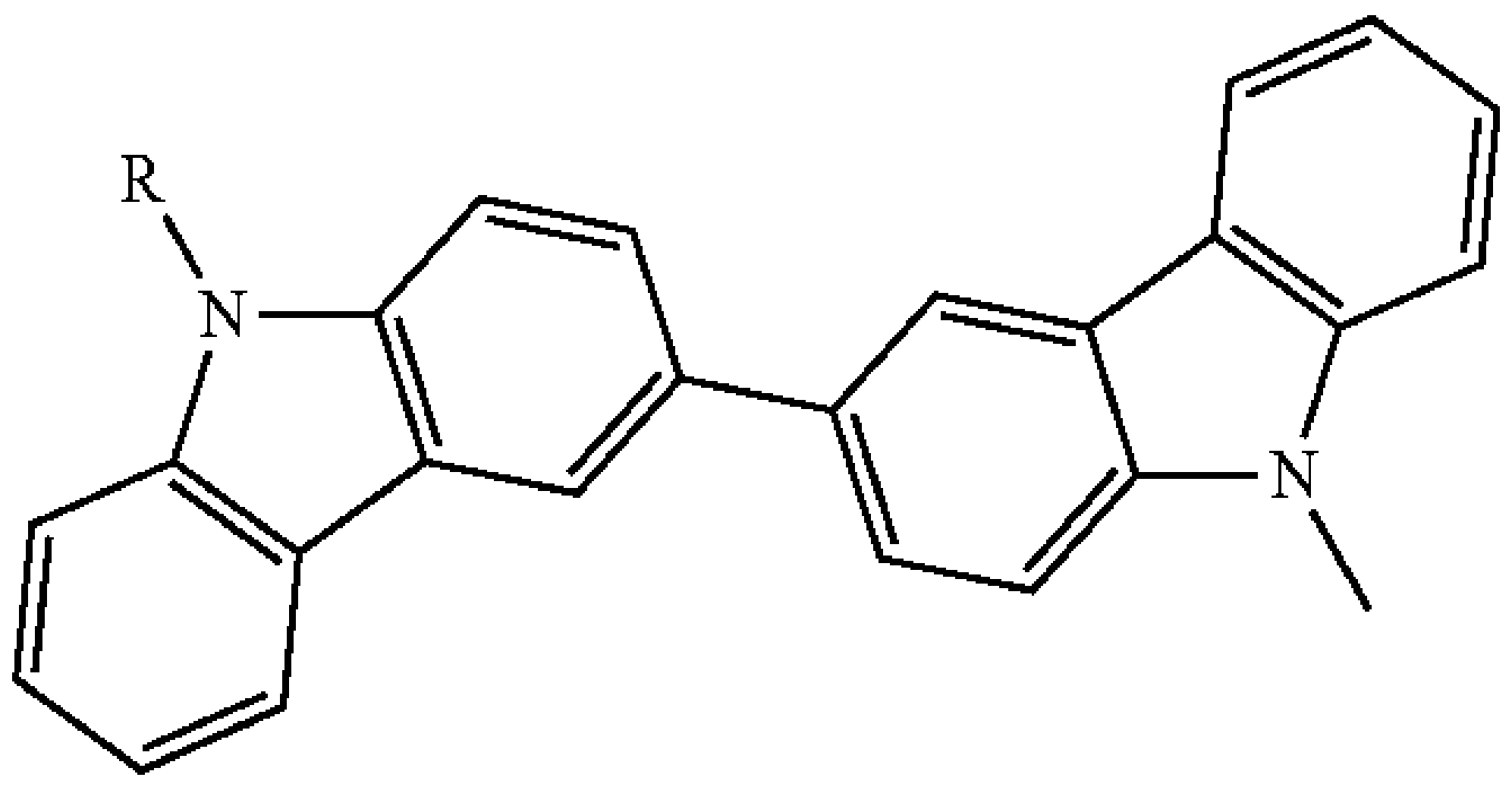

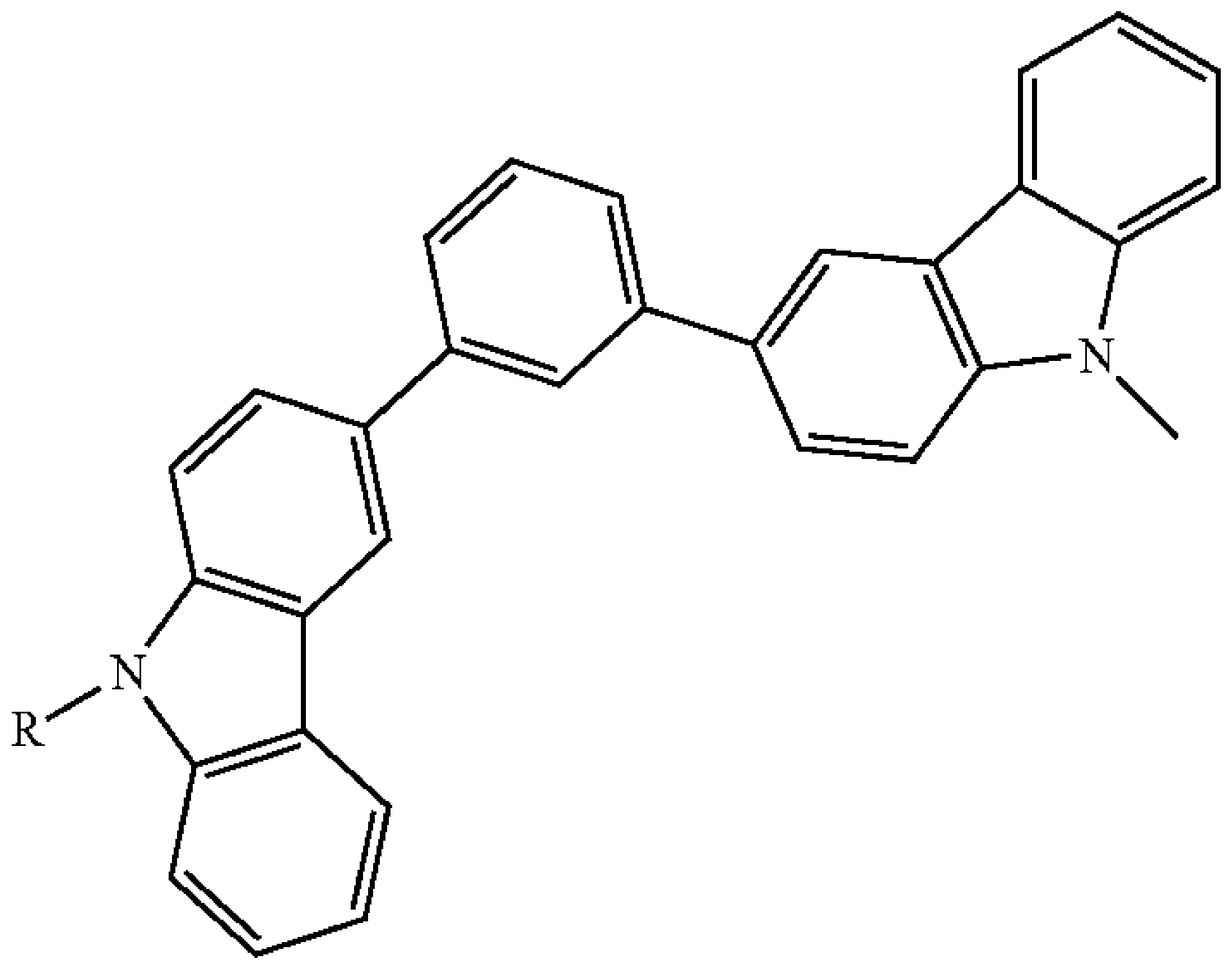

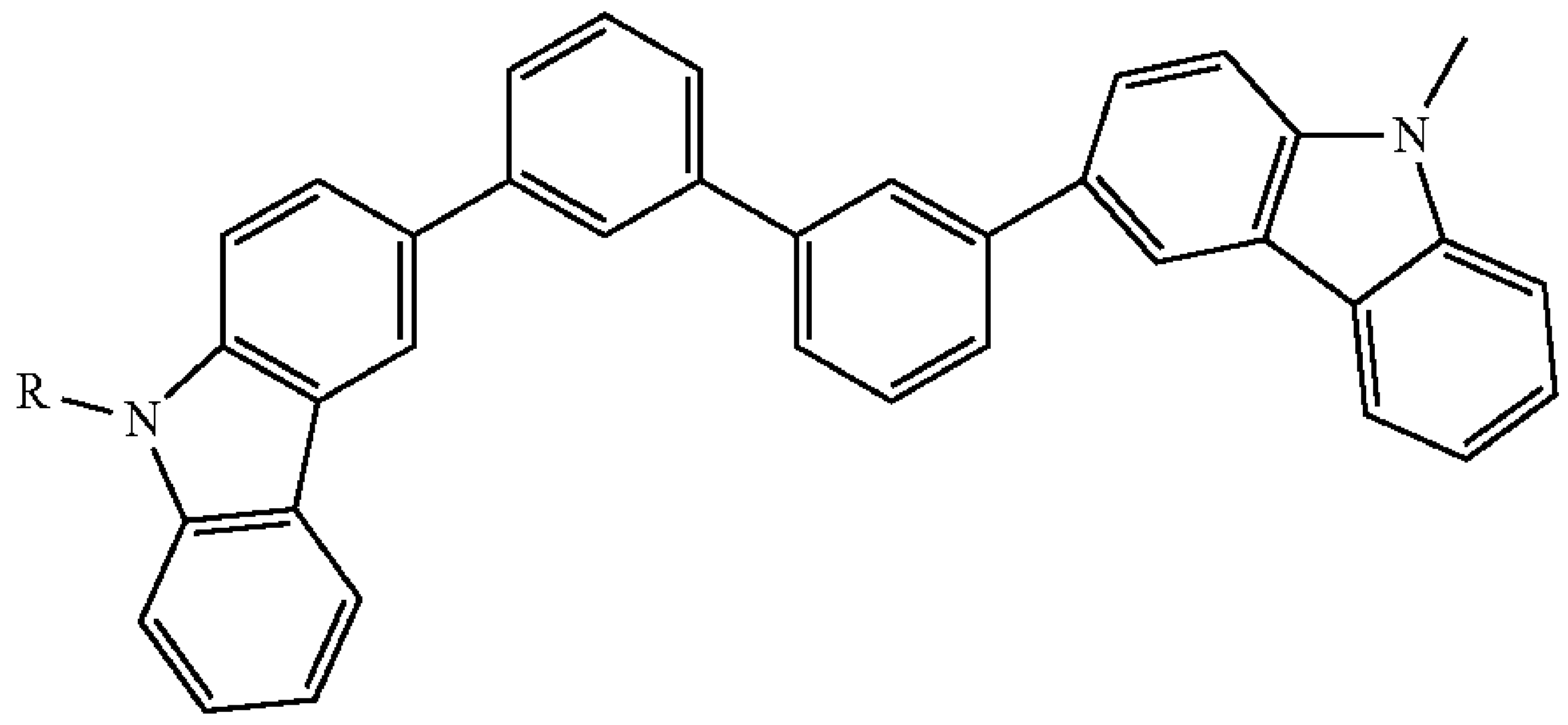

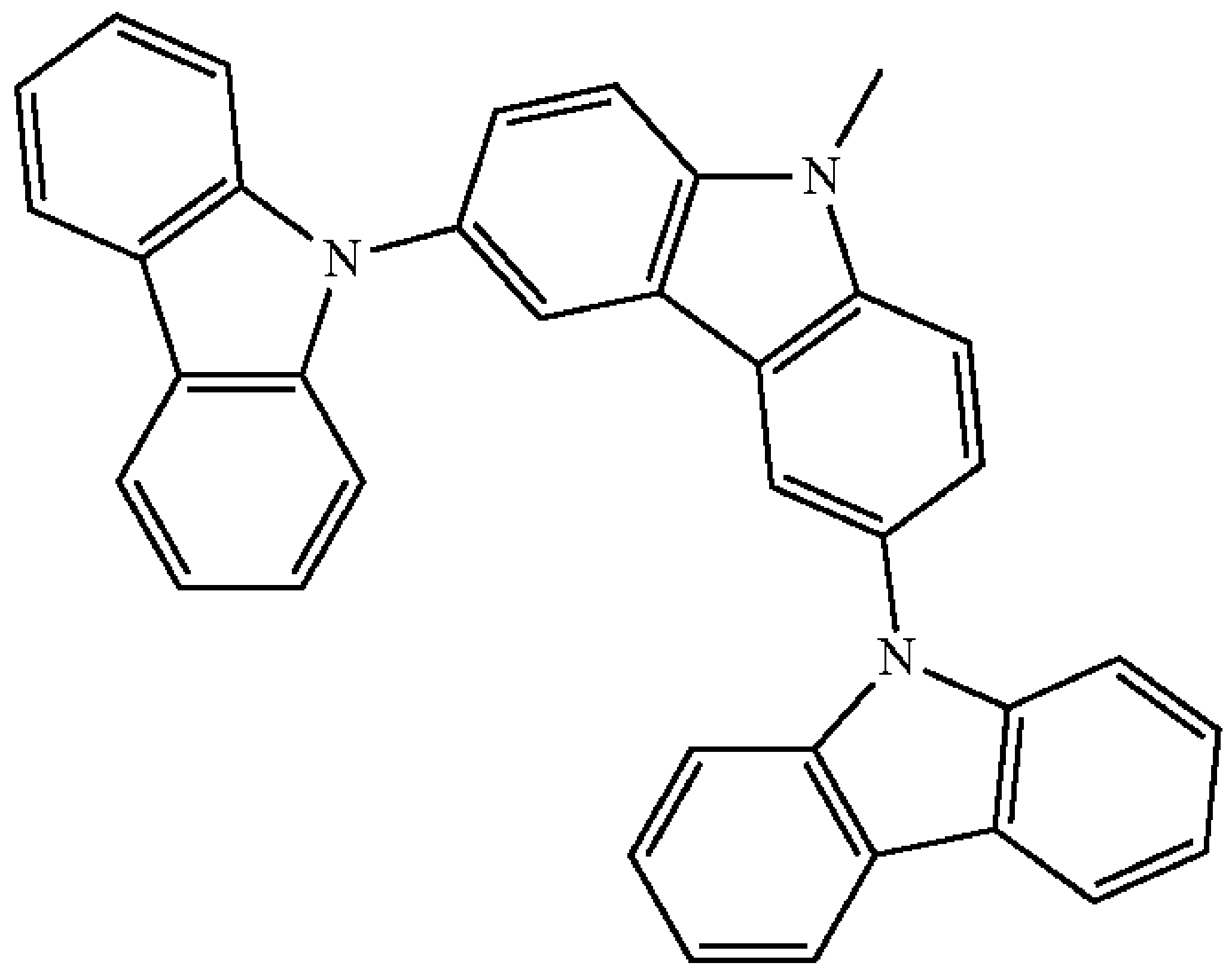

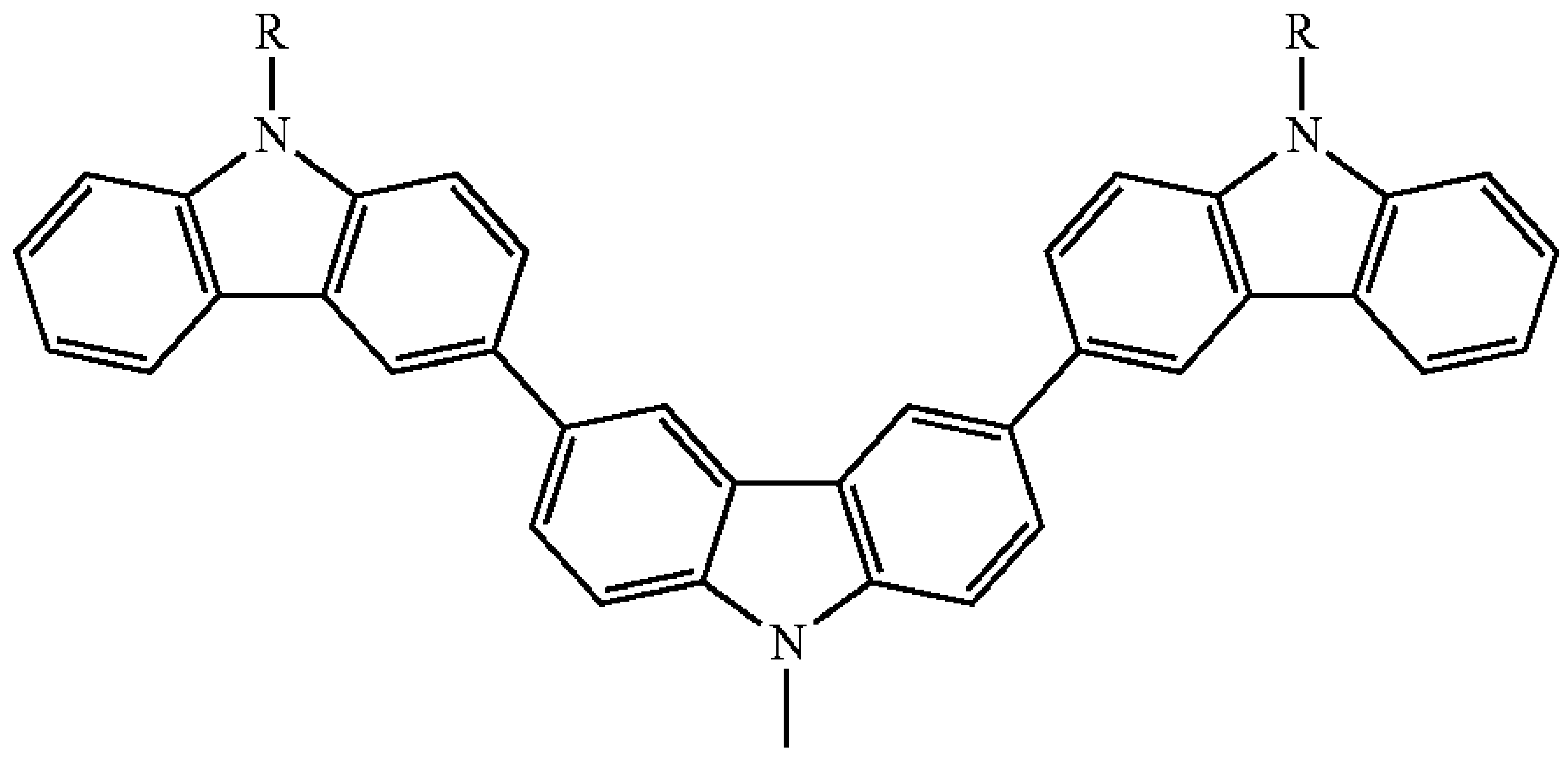

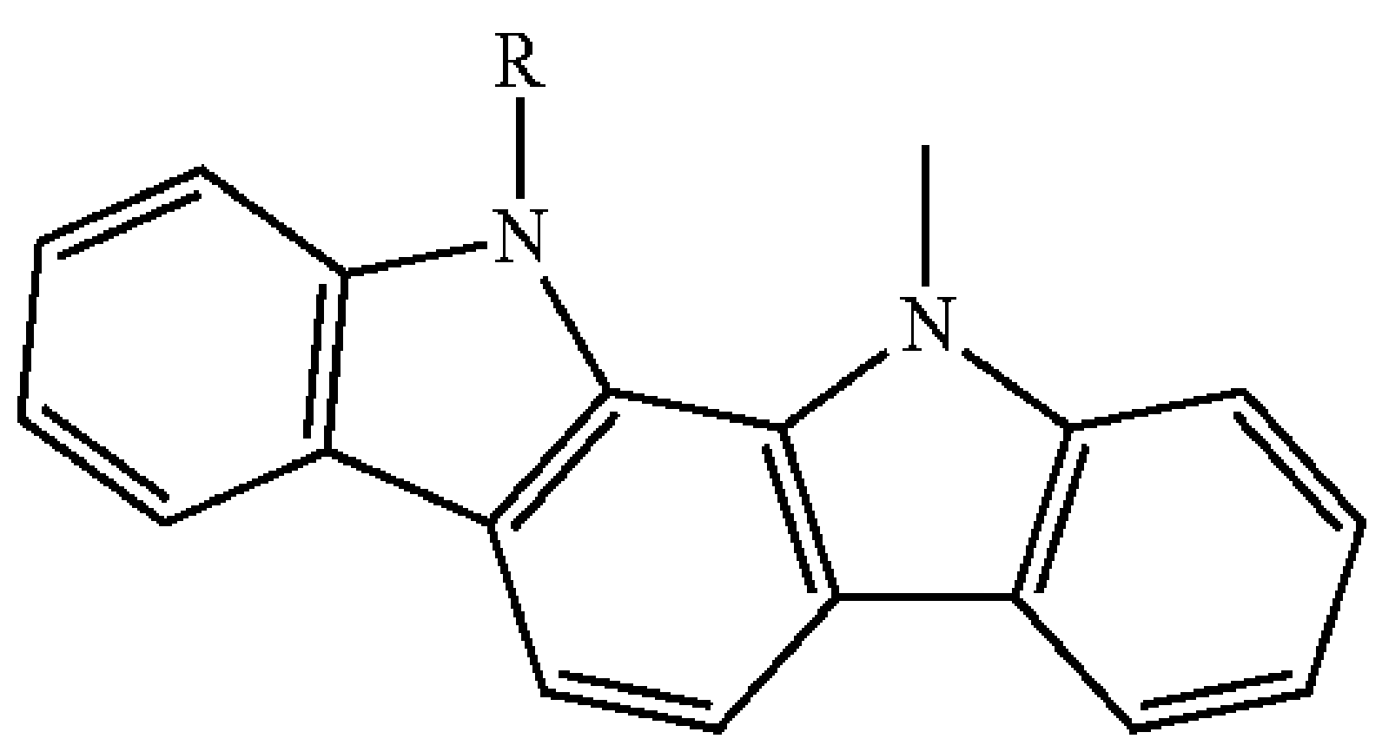

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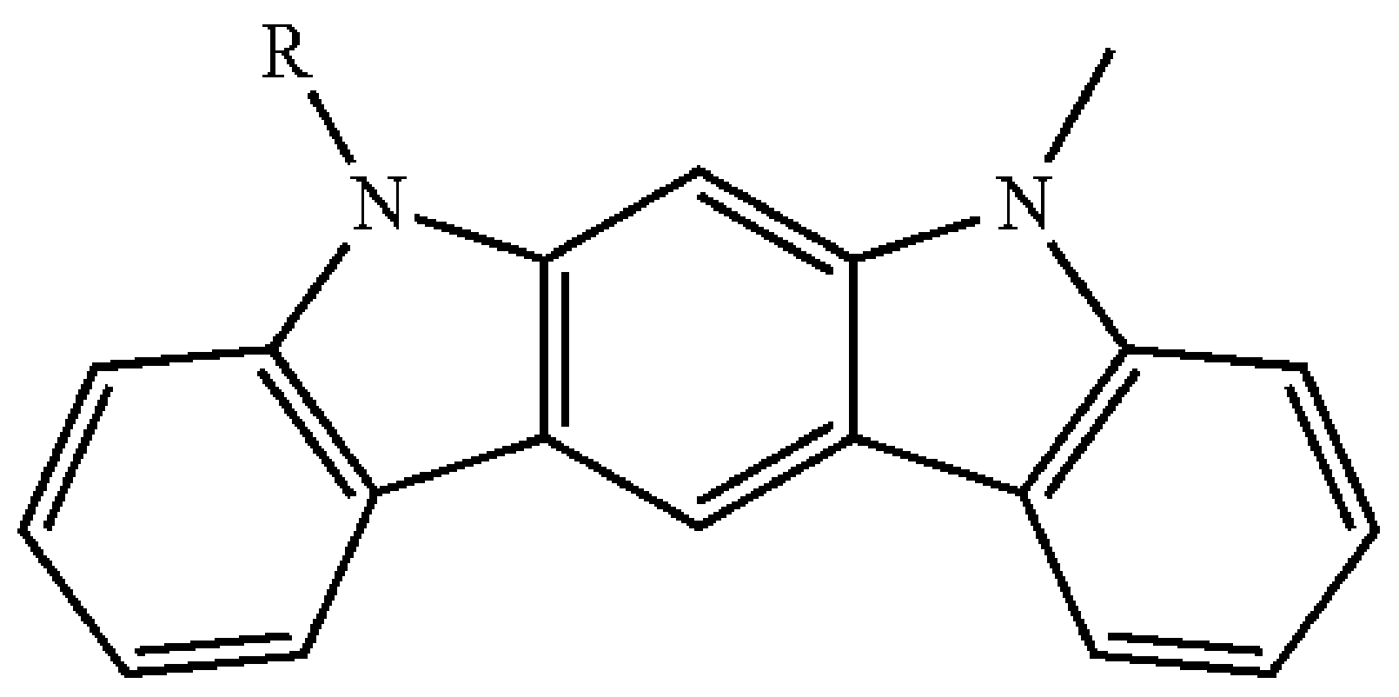

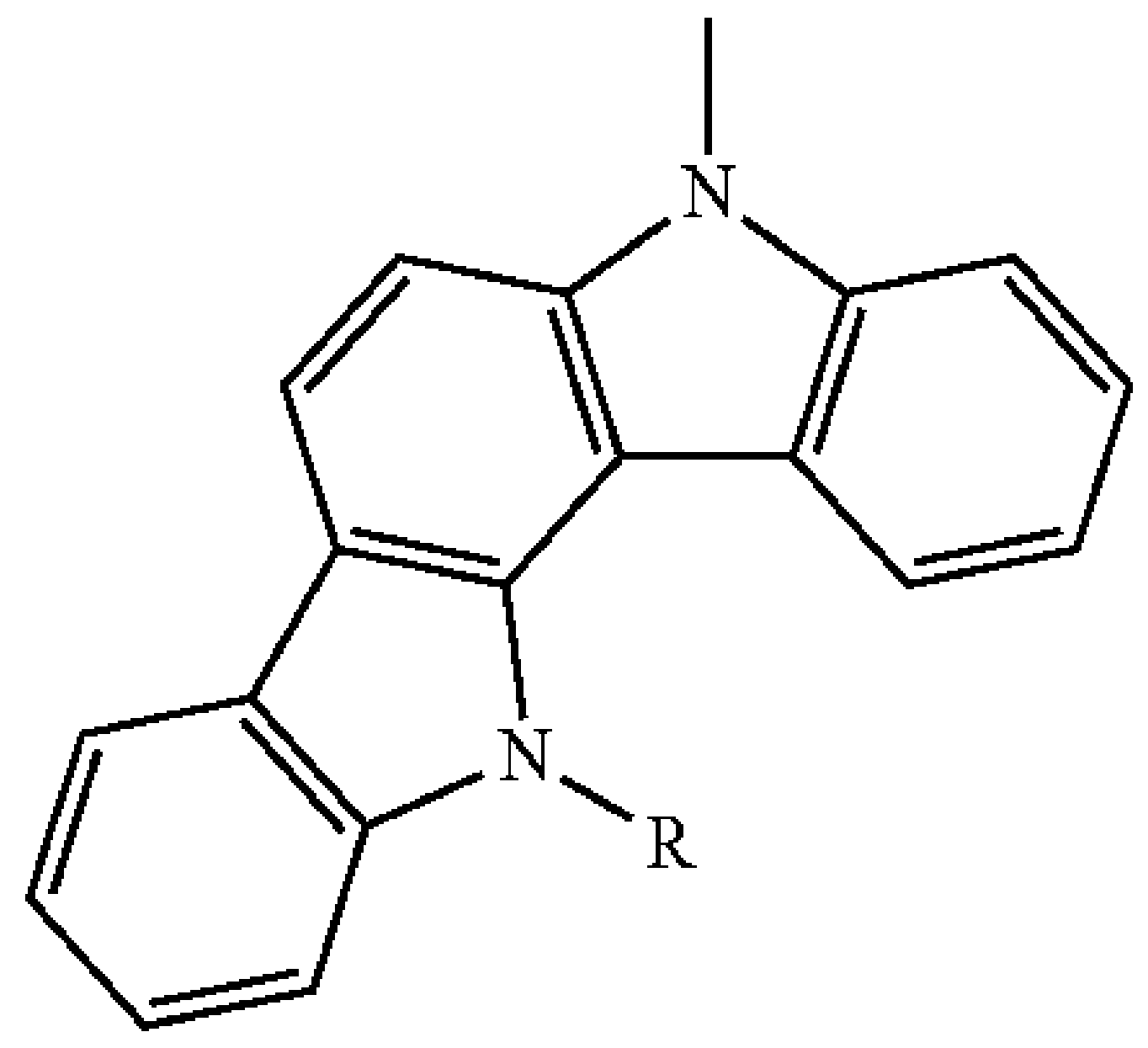

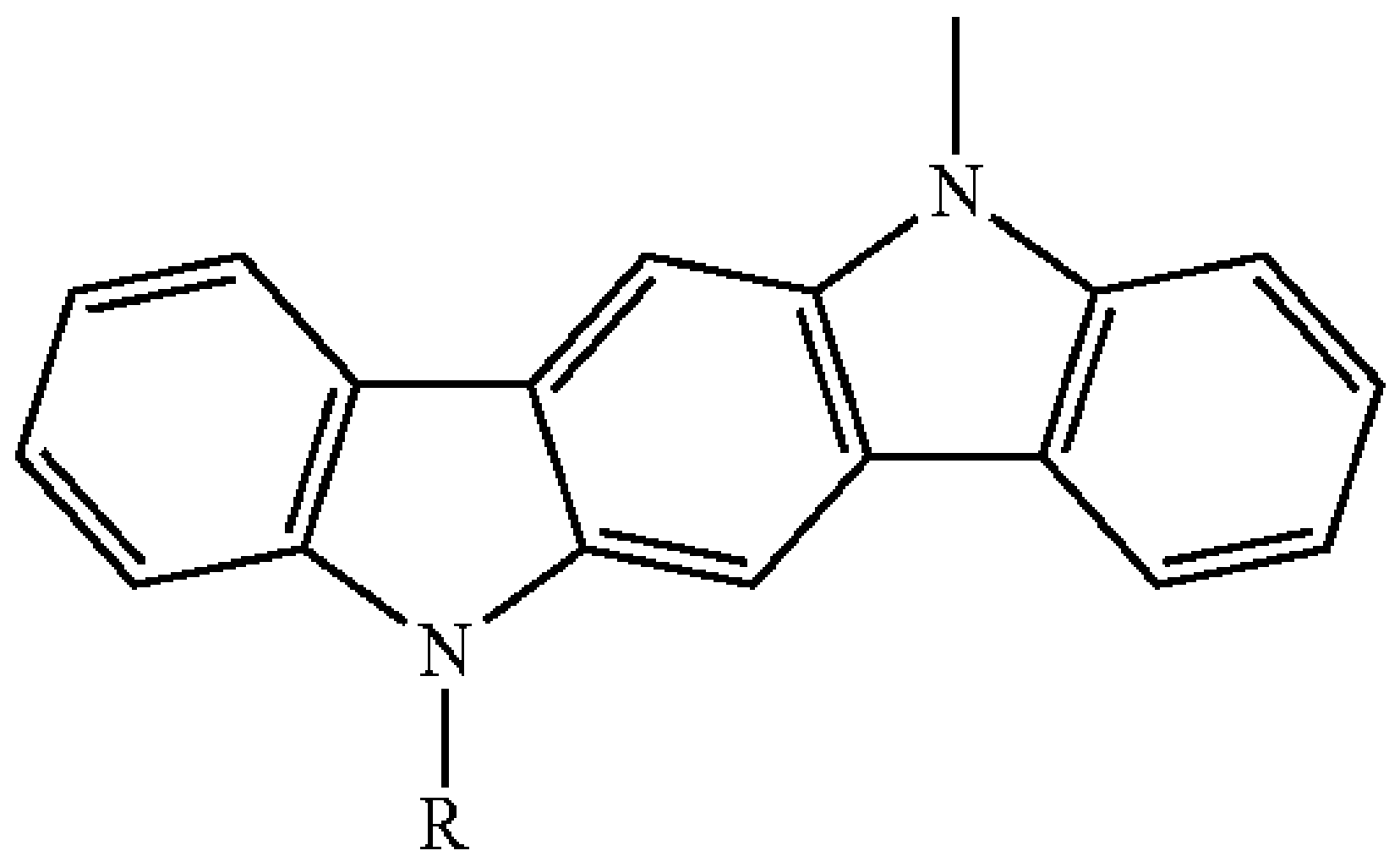

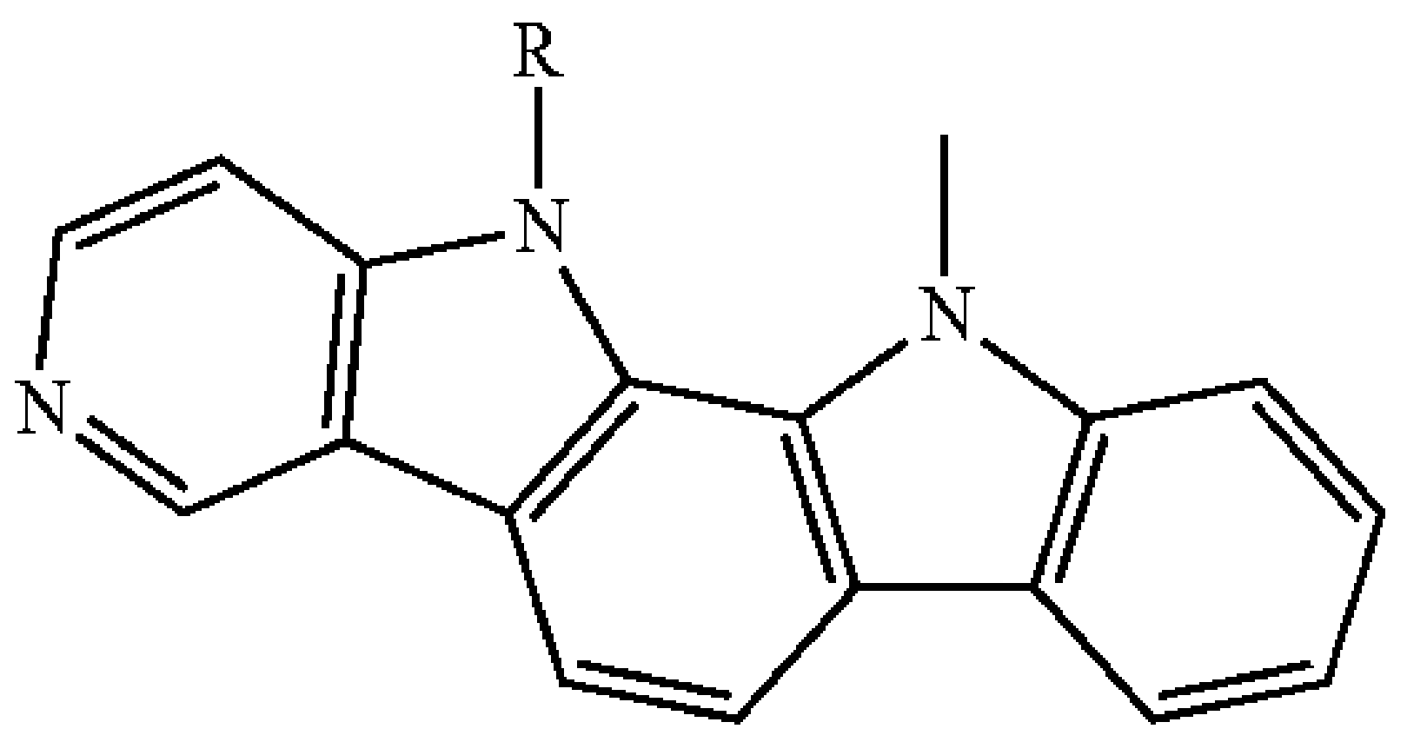

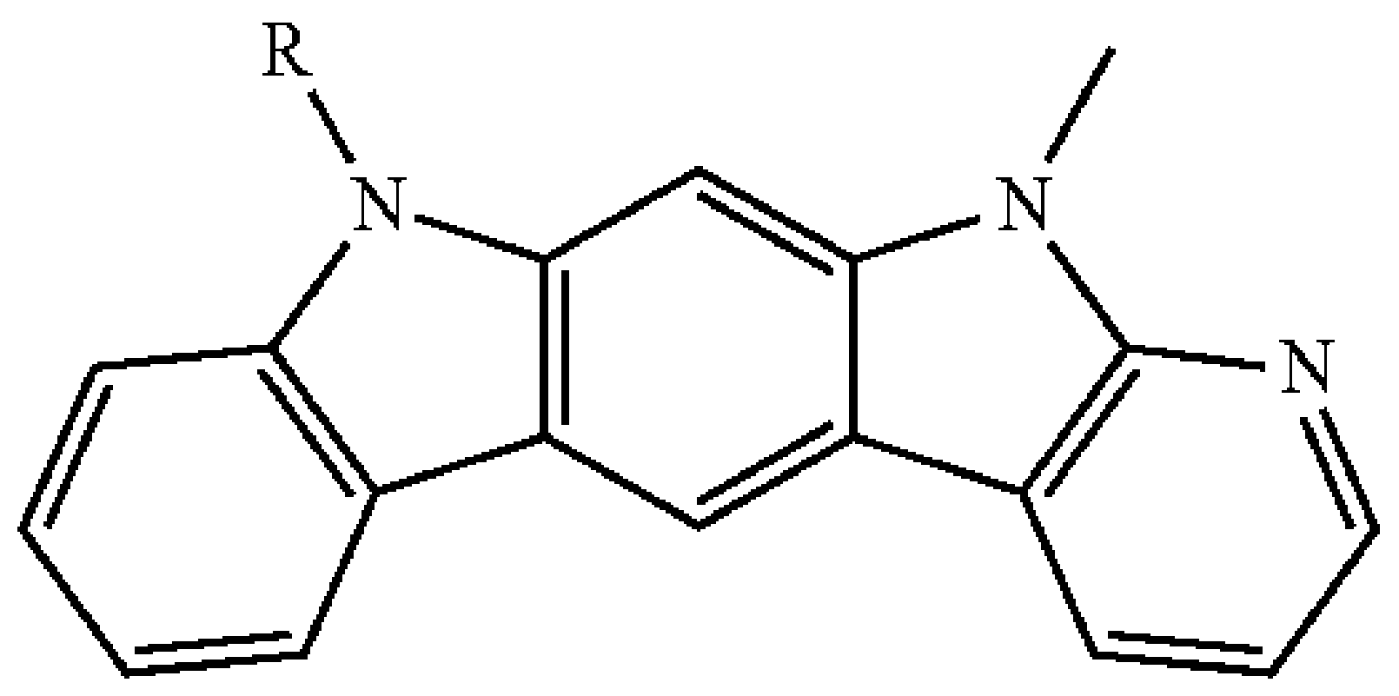

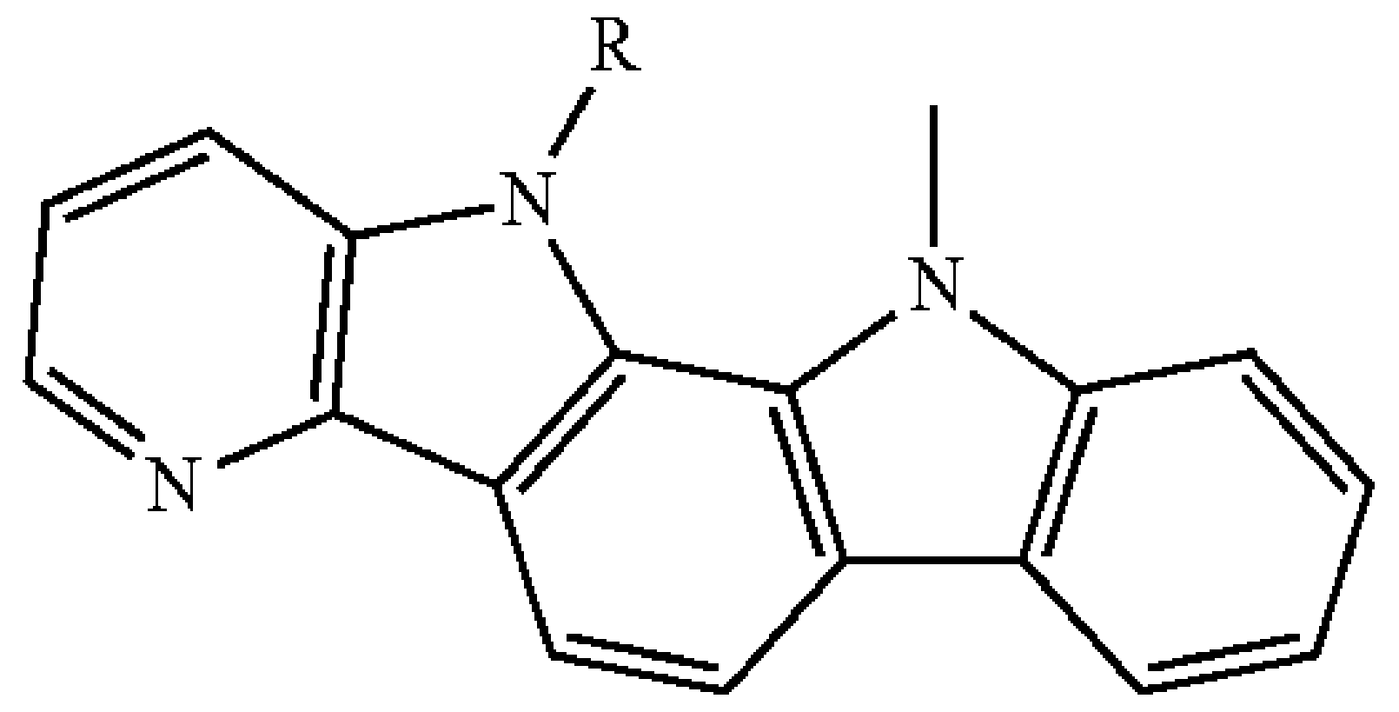

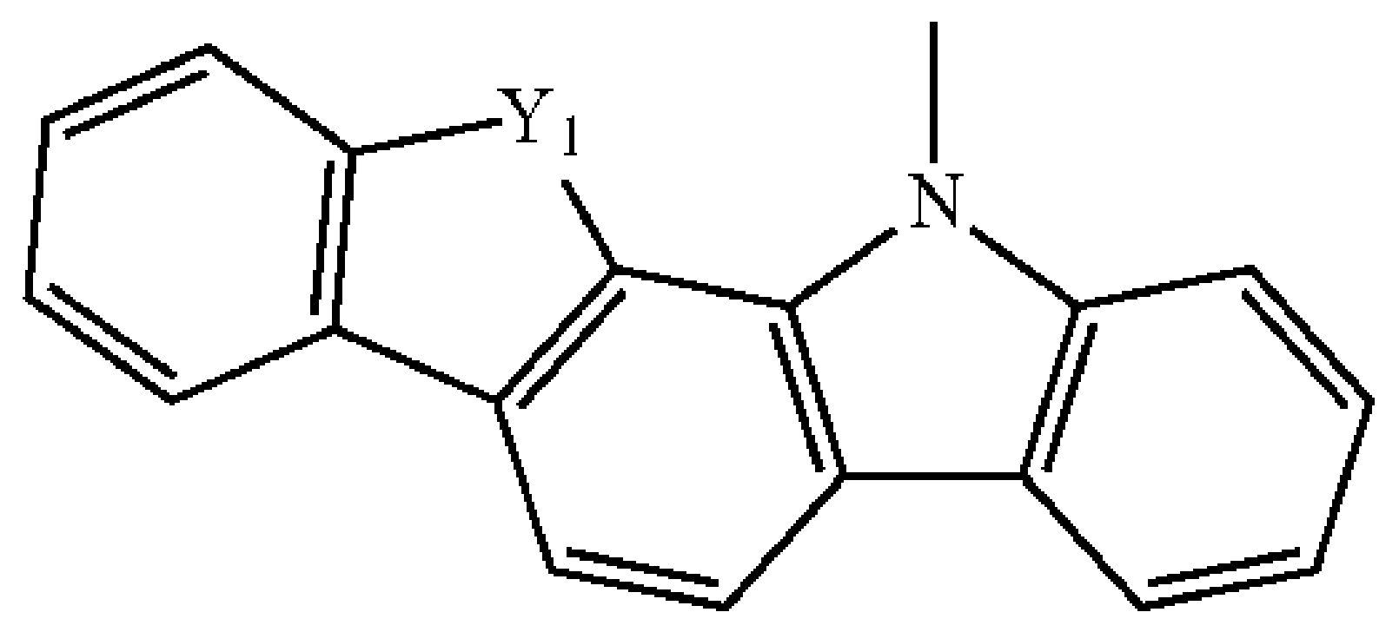

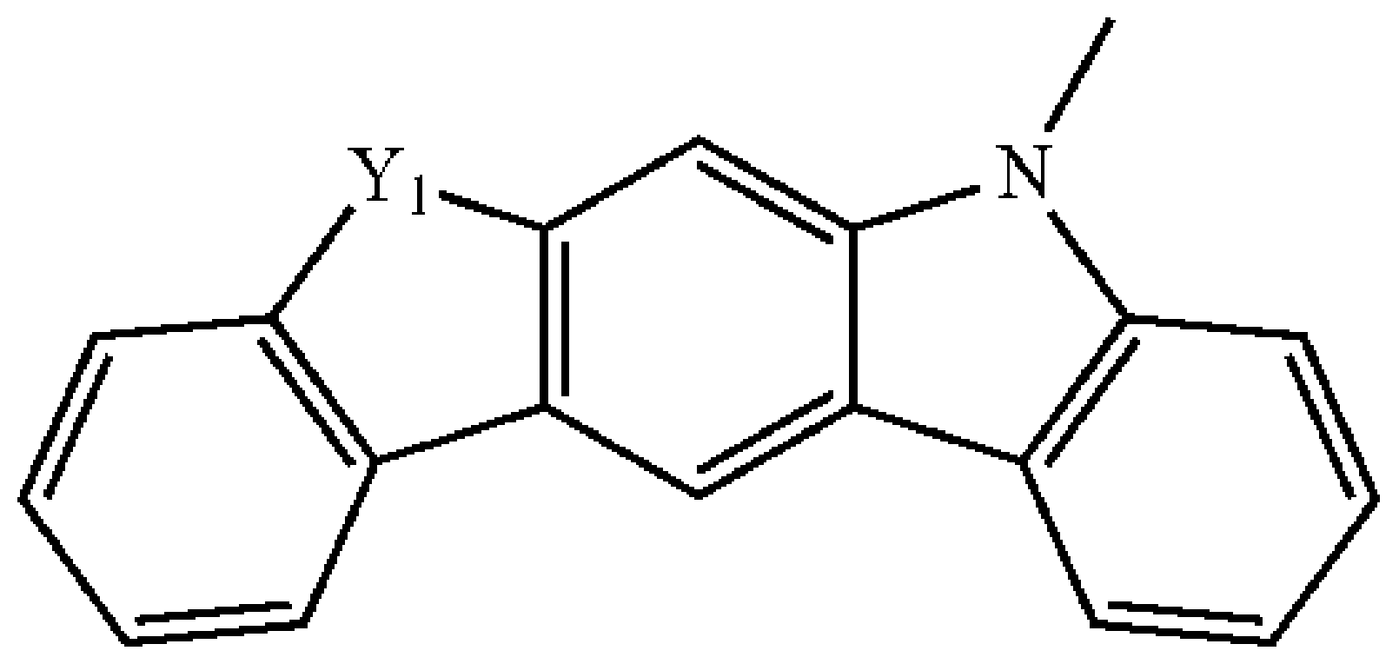

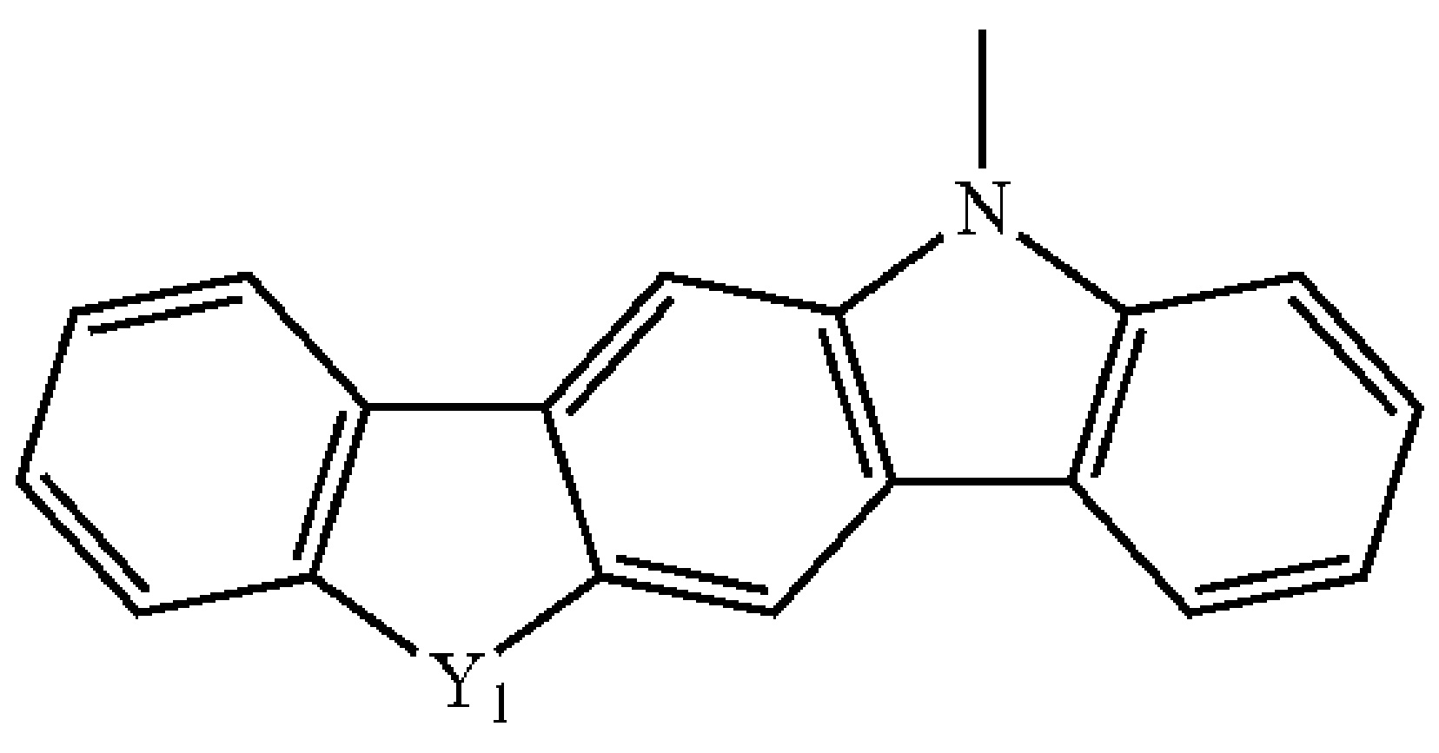

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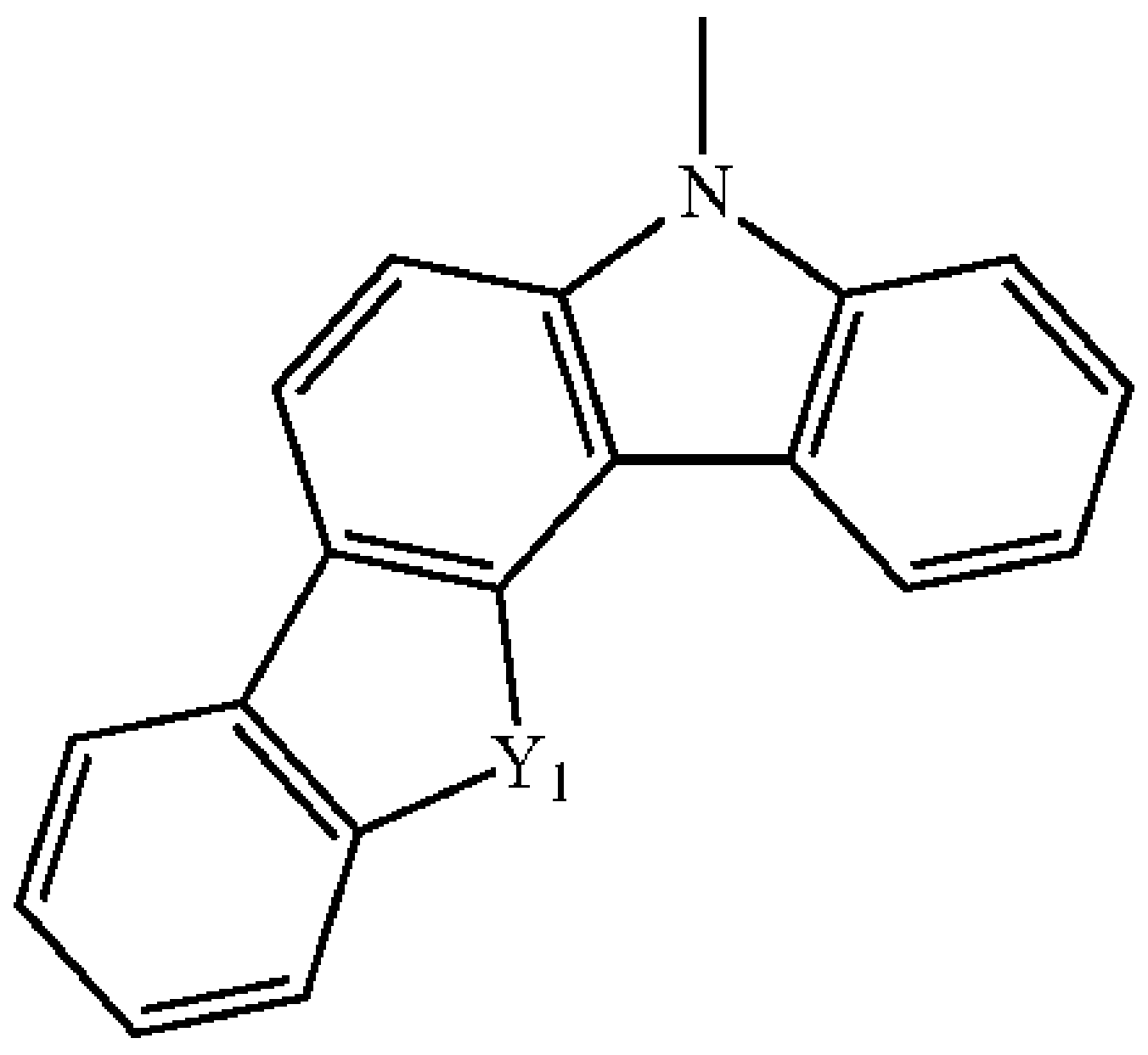
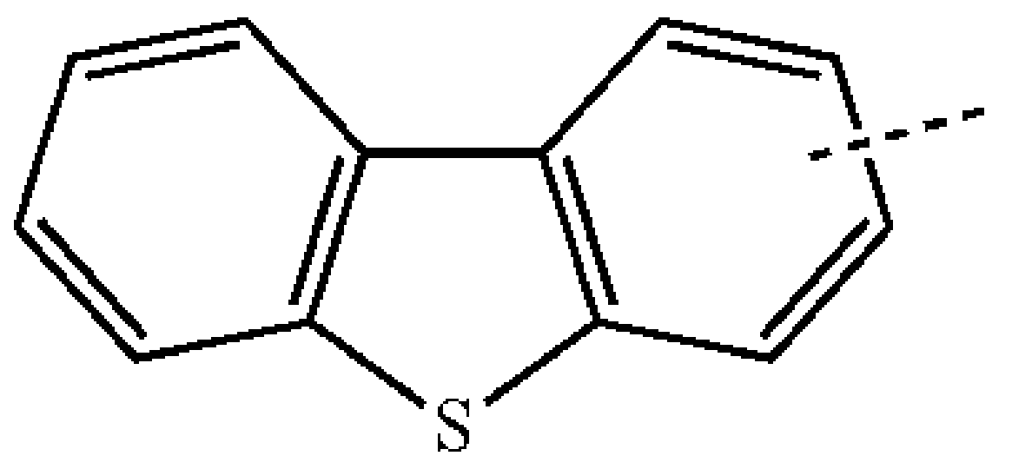
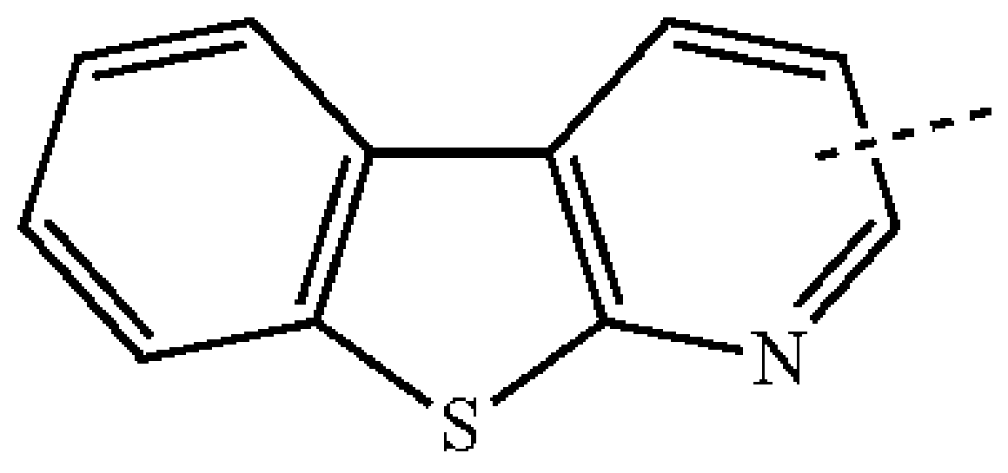
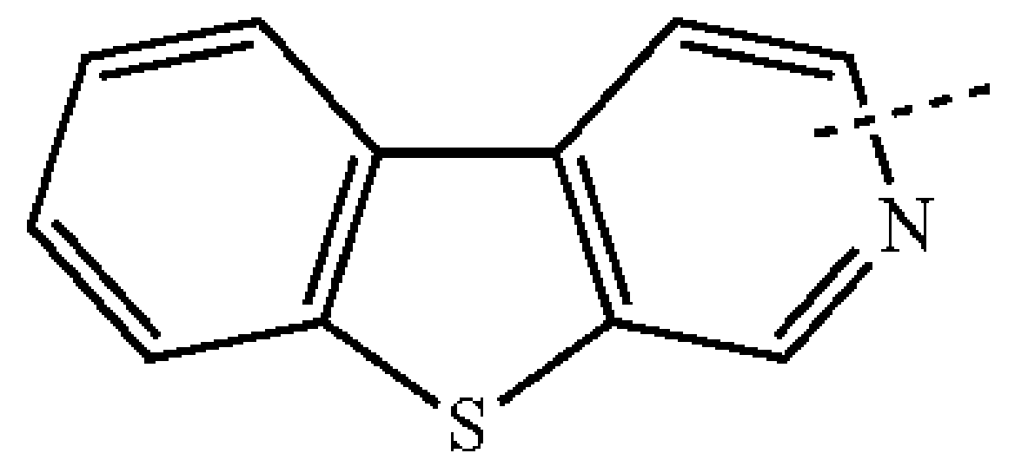
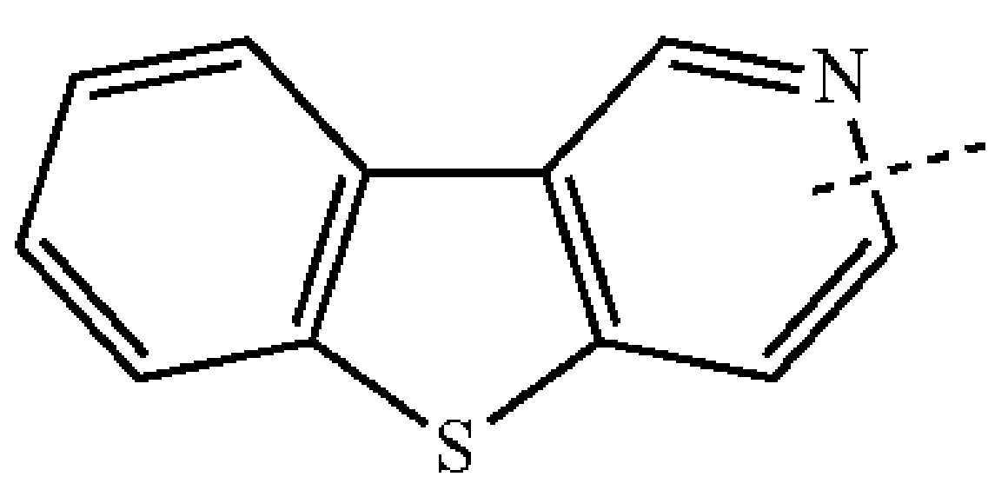
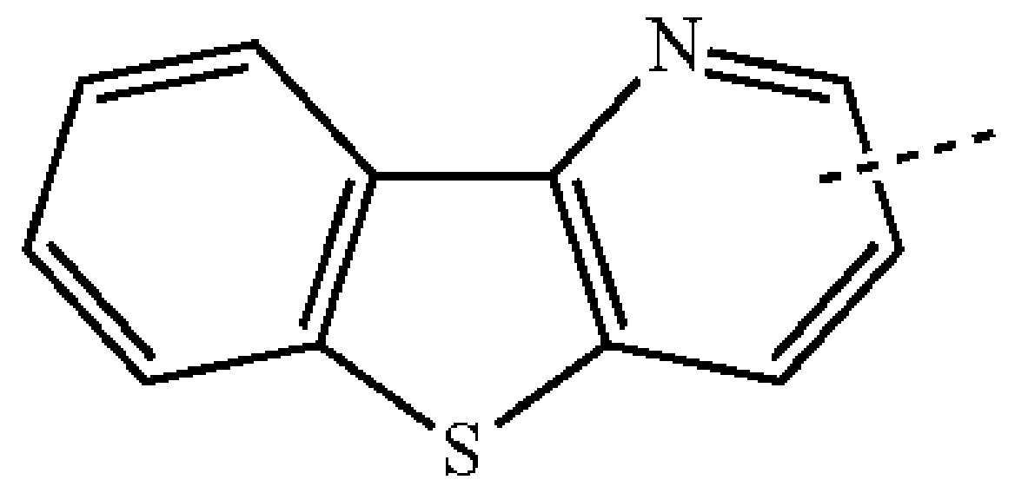


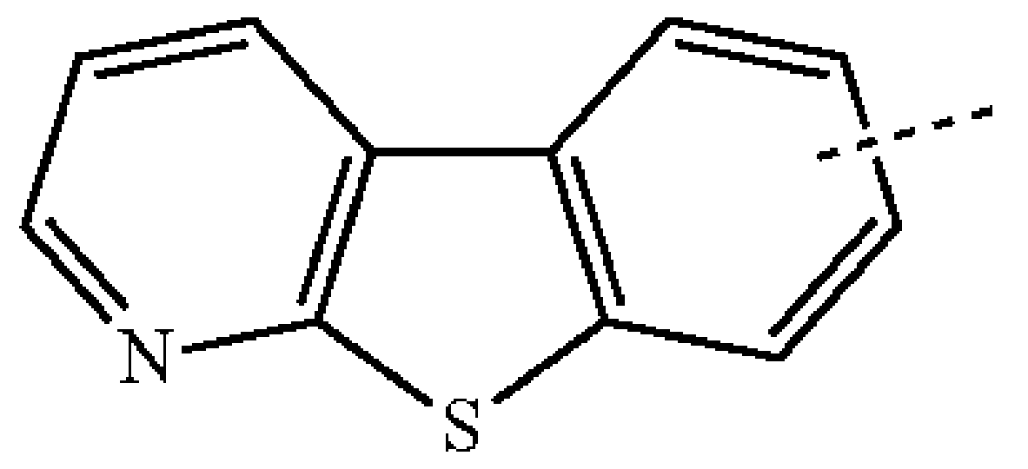


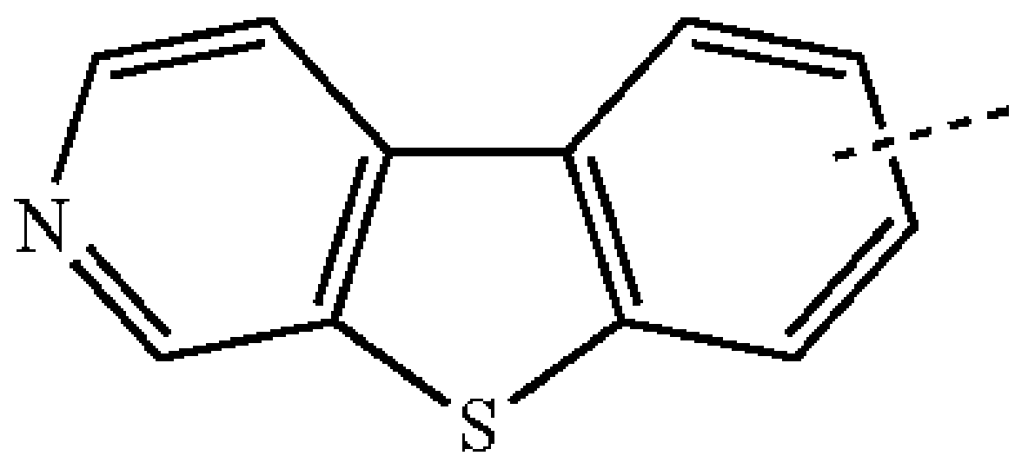


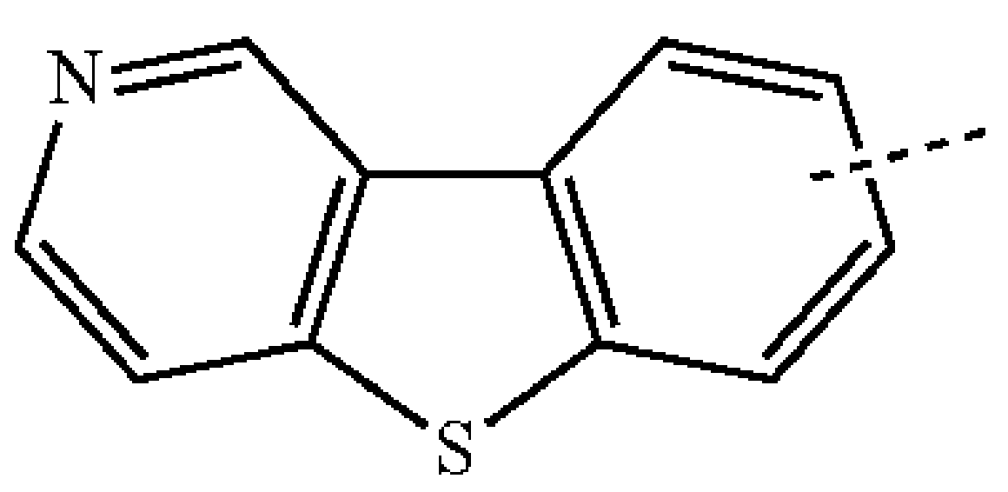


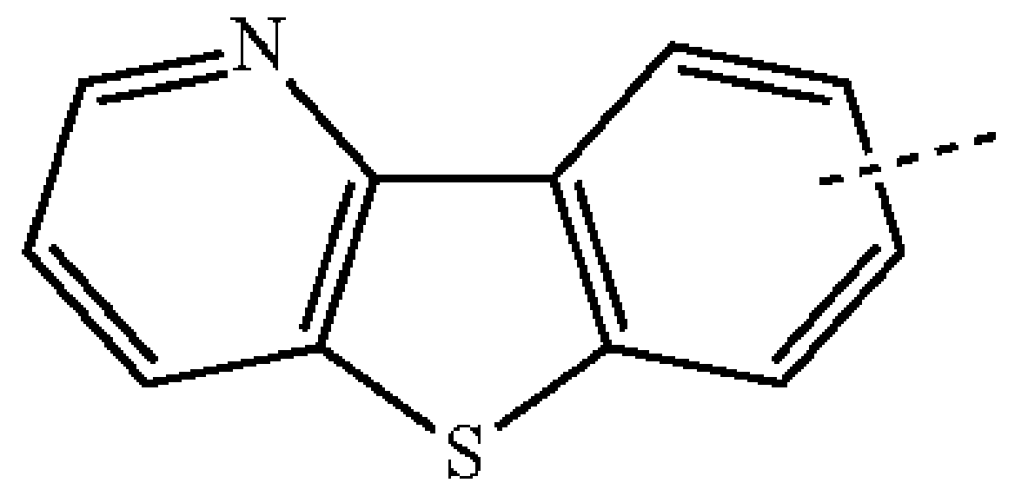


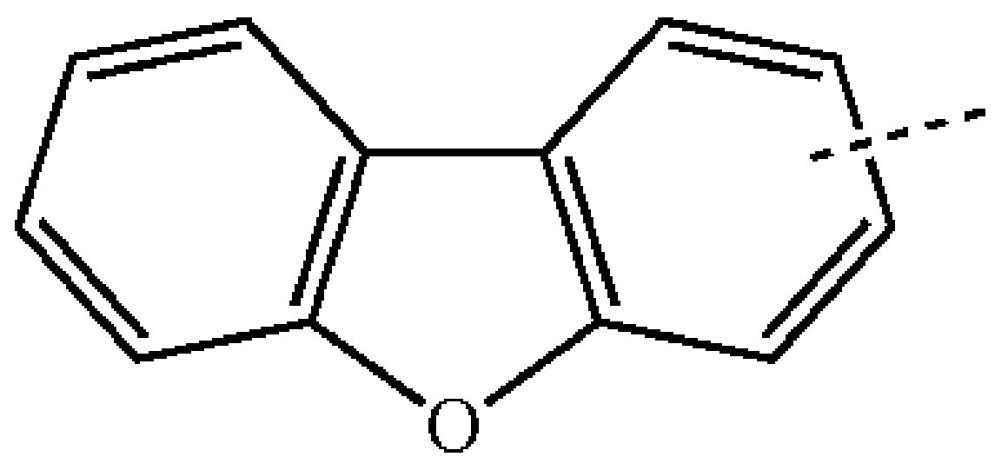


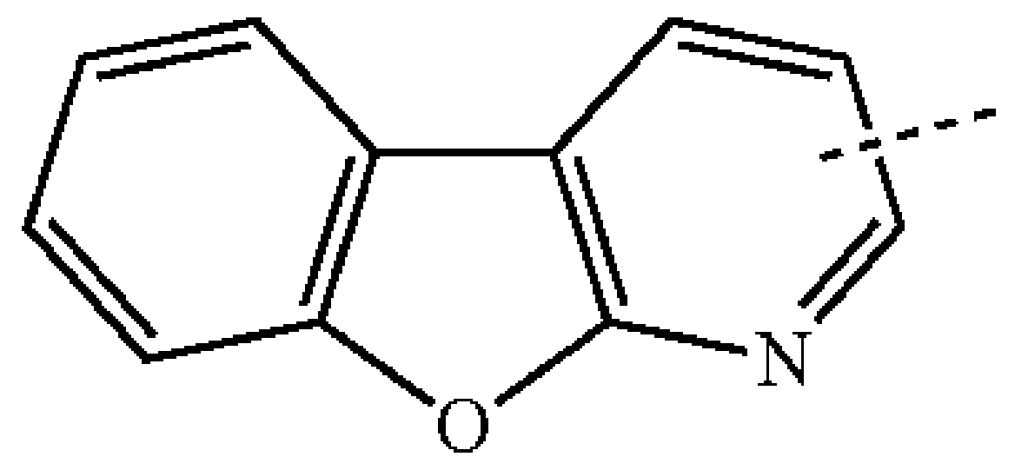


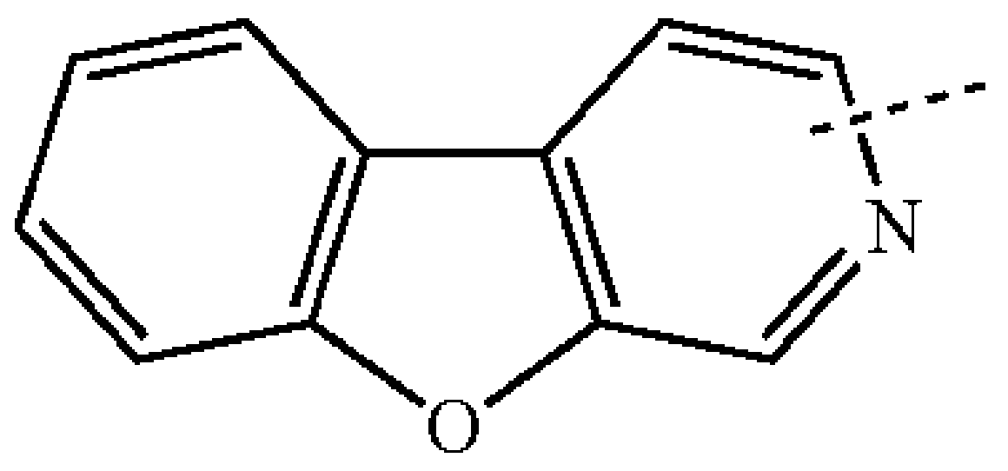


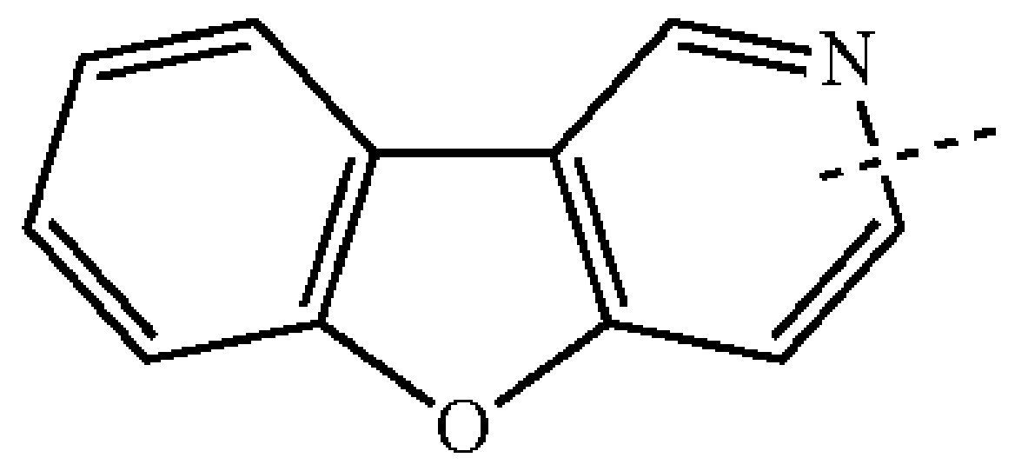


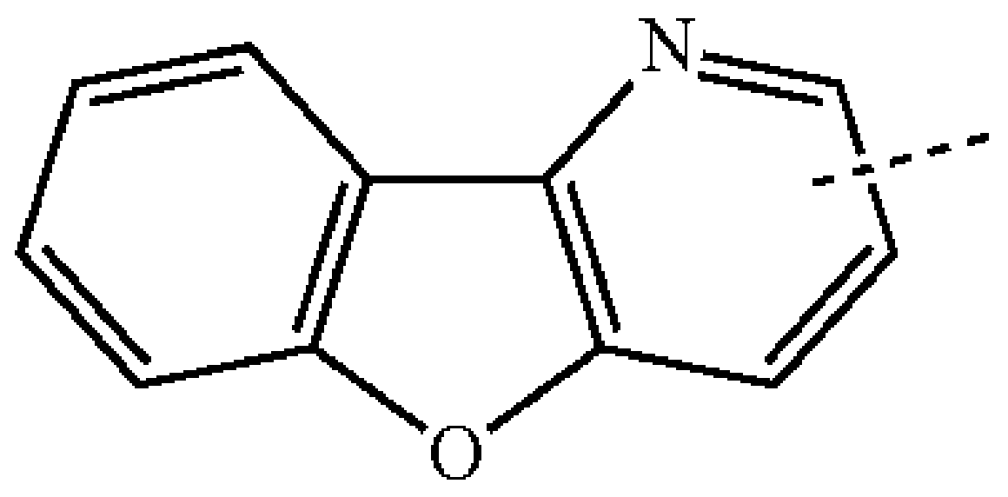


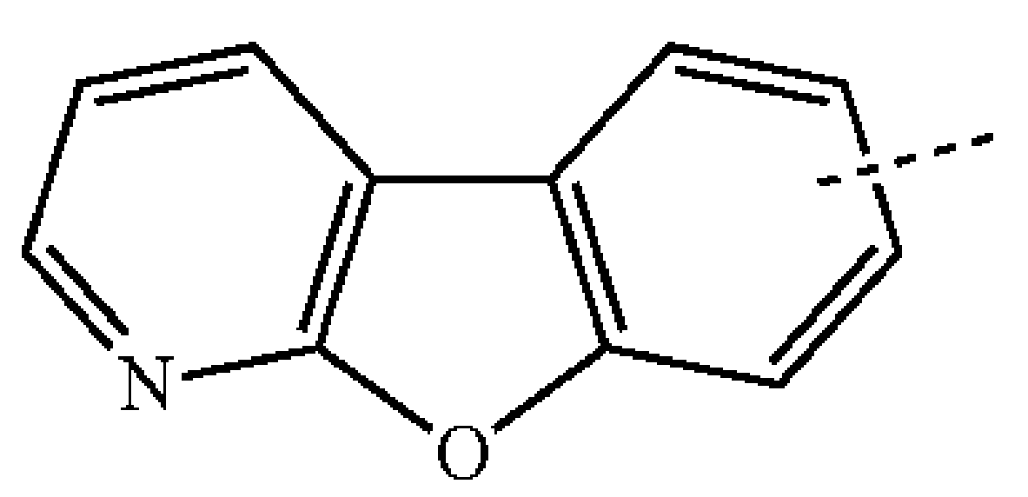


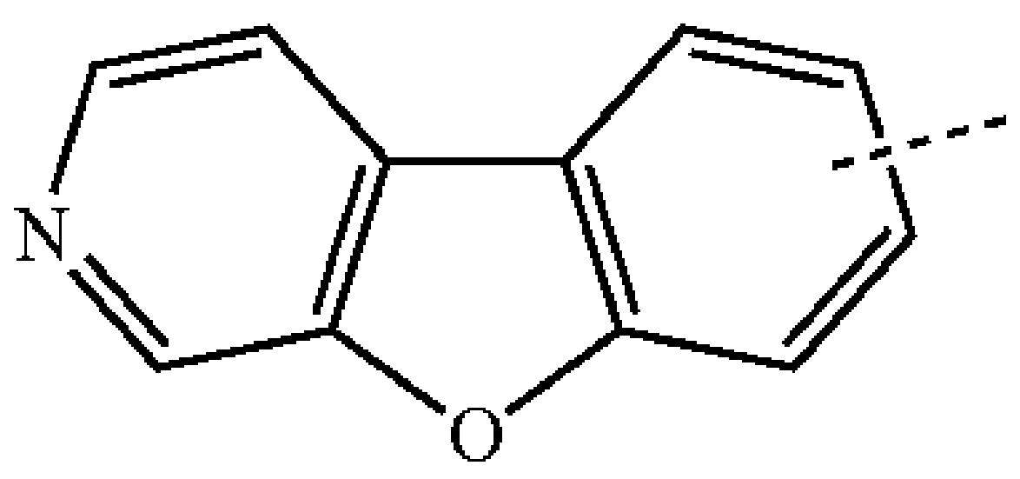


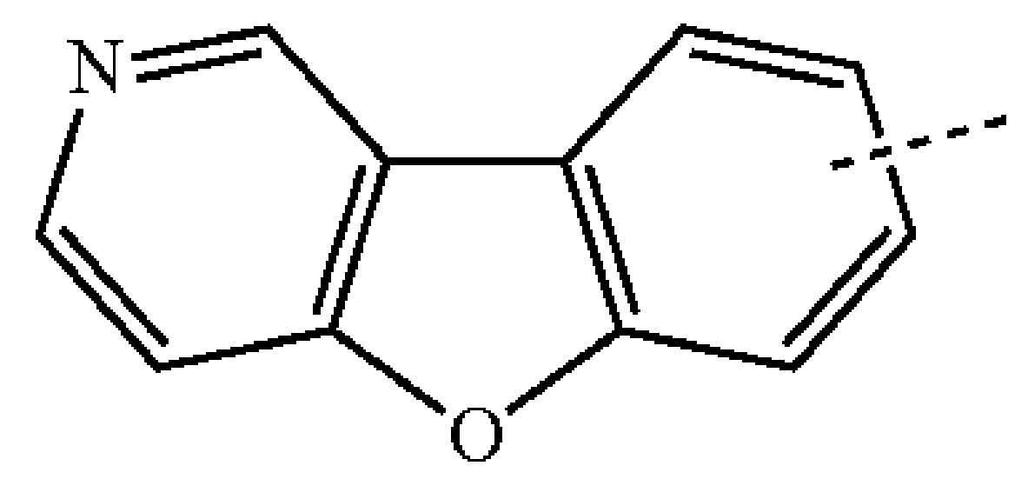


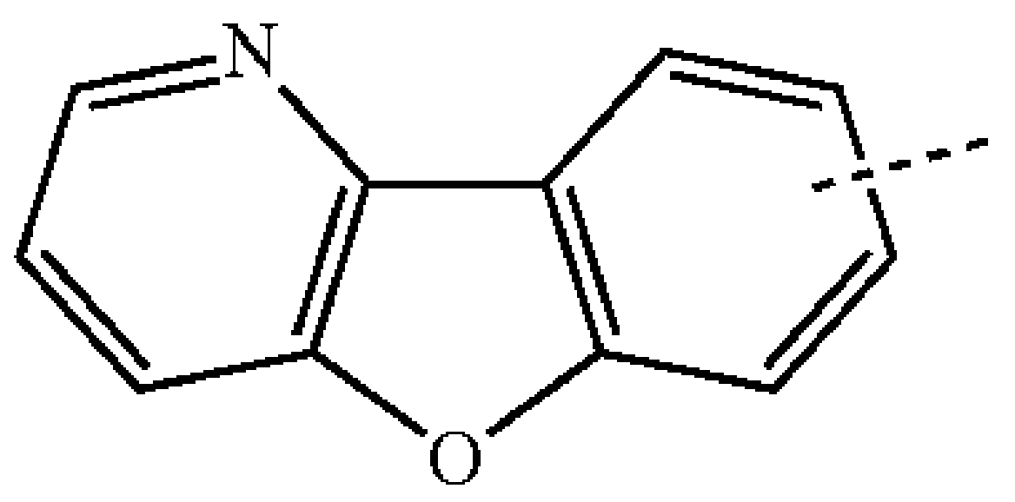






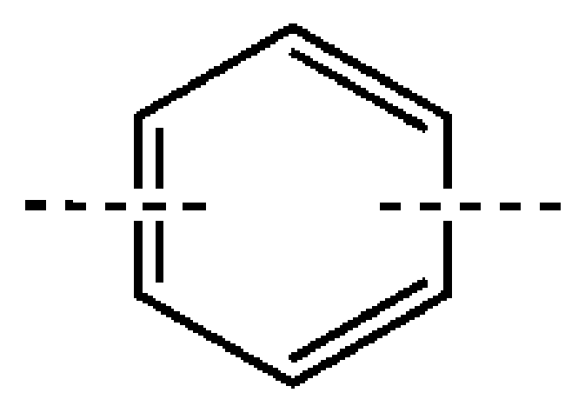


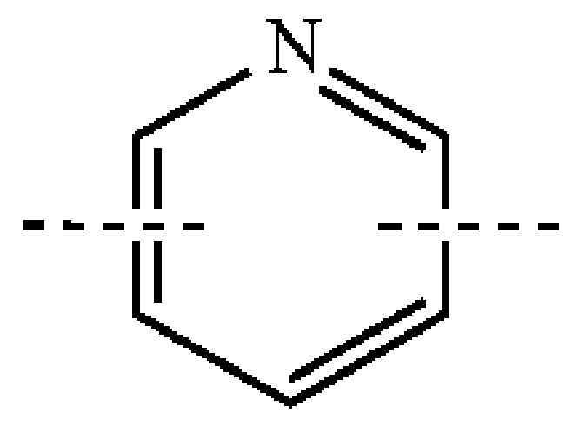


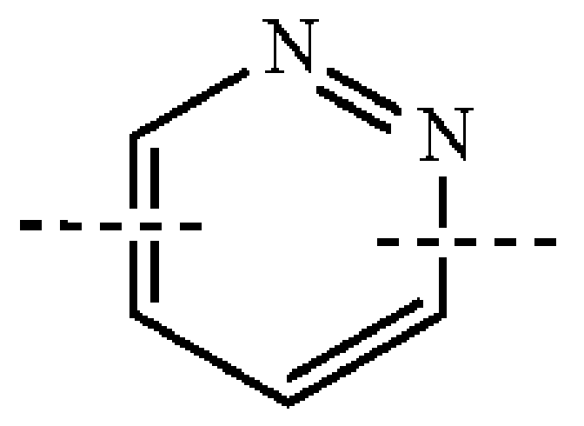


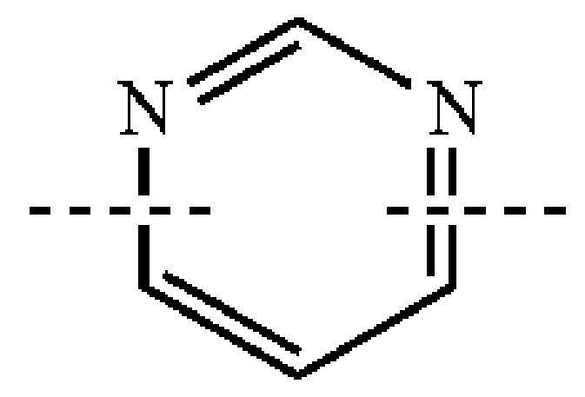
wherein Y_1 is selected from the group consisting of O, S, and Se, wherein R is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfanyl, sulfonyl, phosphino, and combinations thereof.

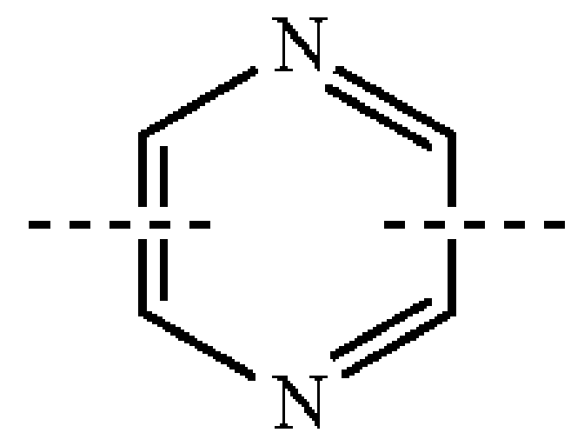
In one aspect, L is independently selected from the group consisting of:

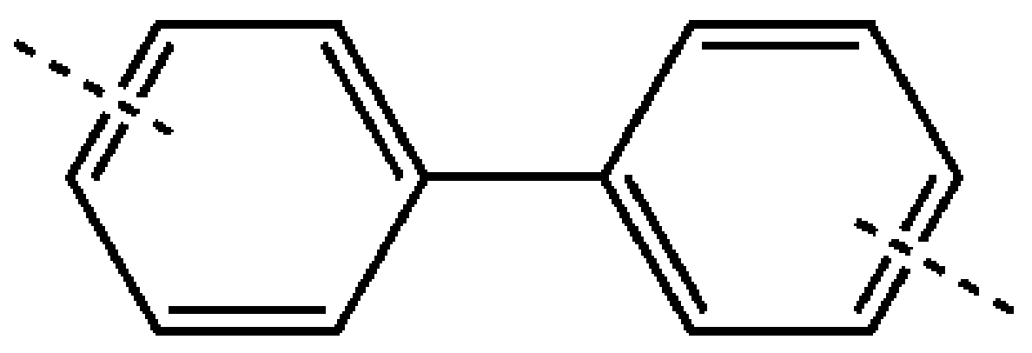


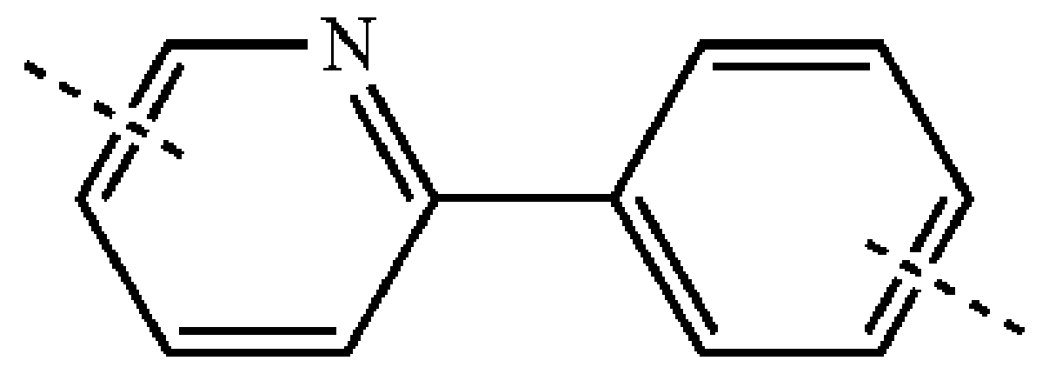


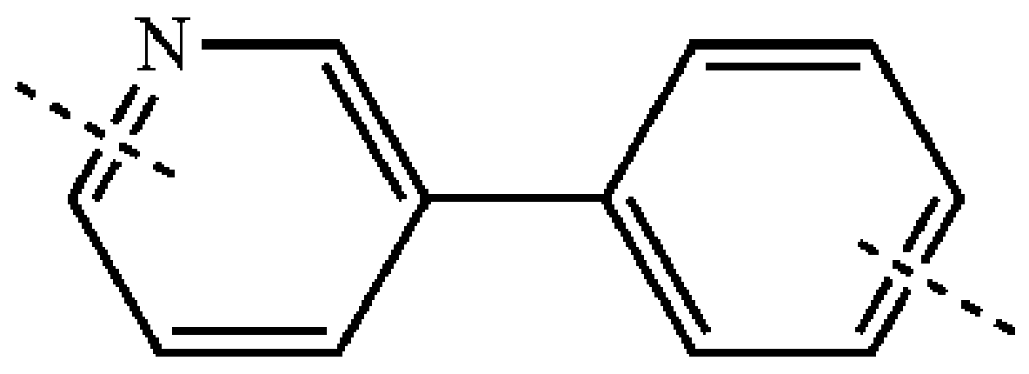


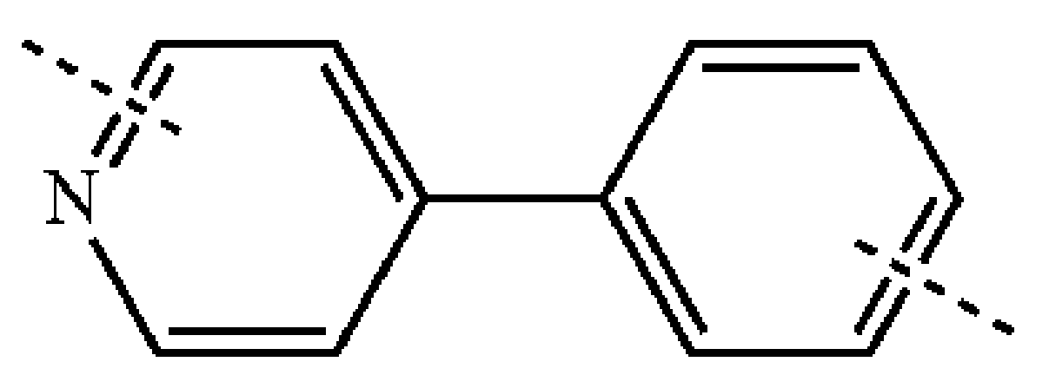


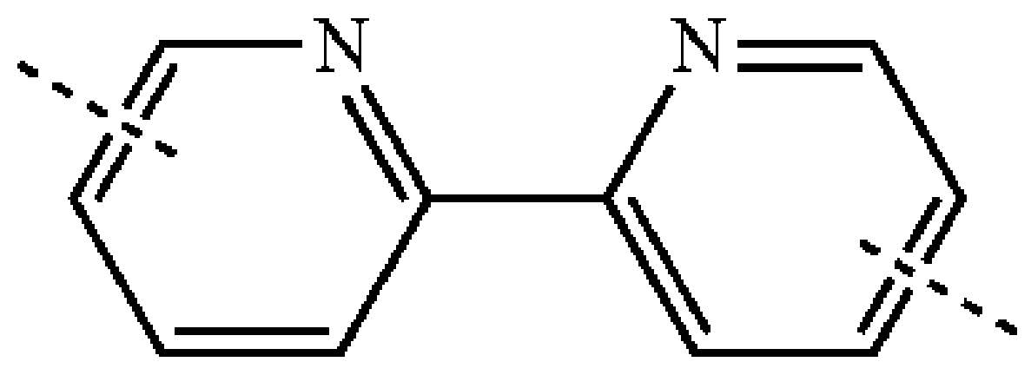


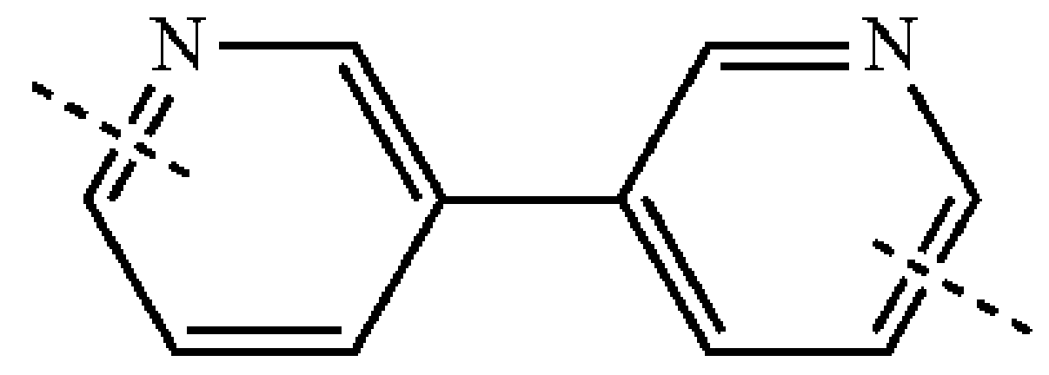


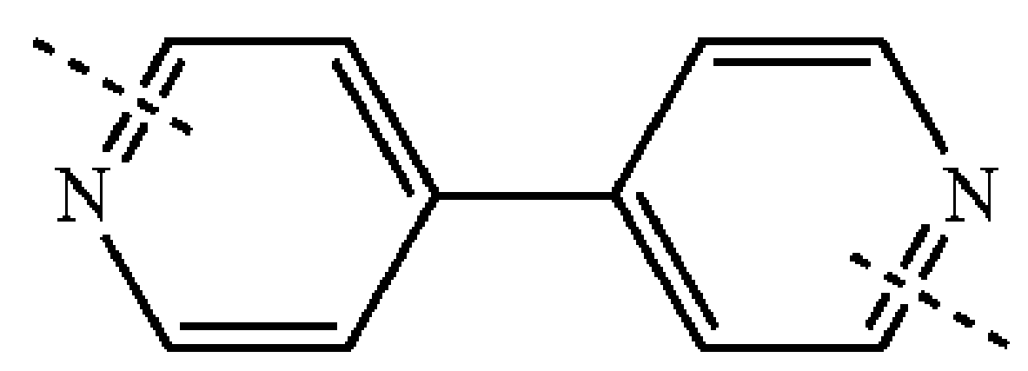


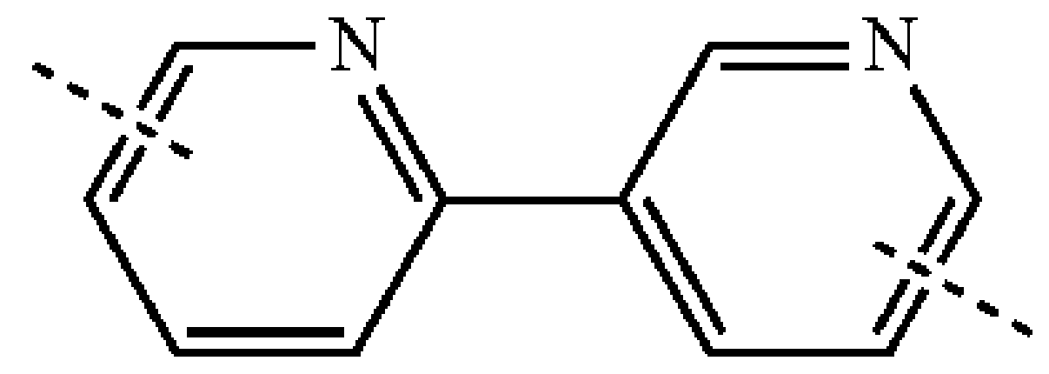


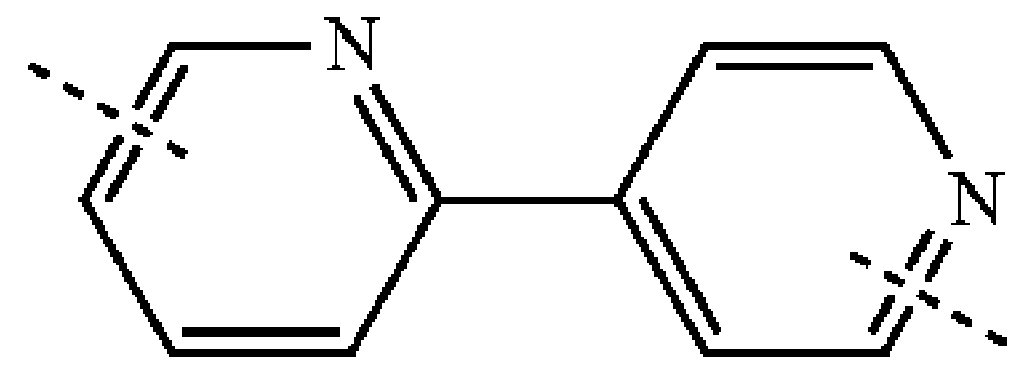


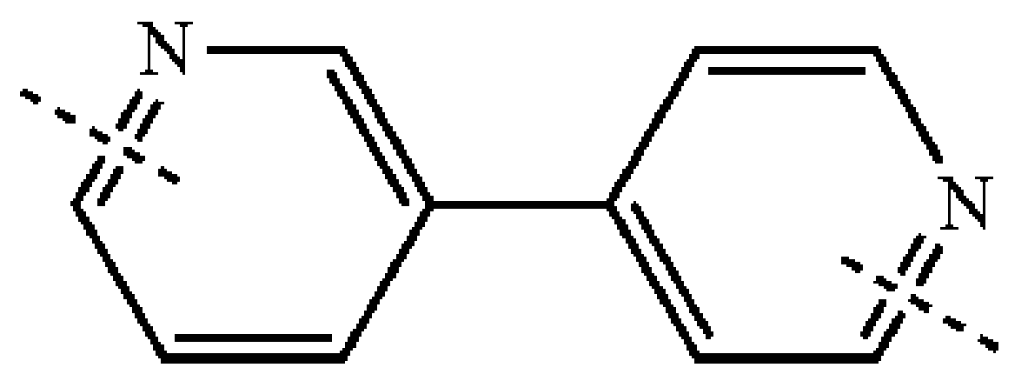


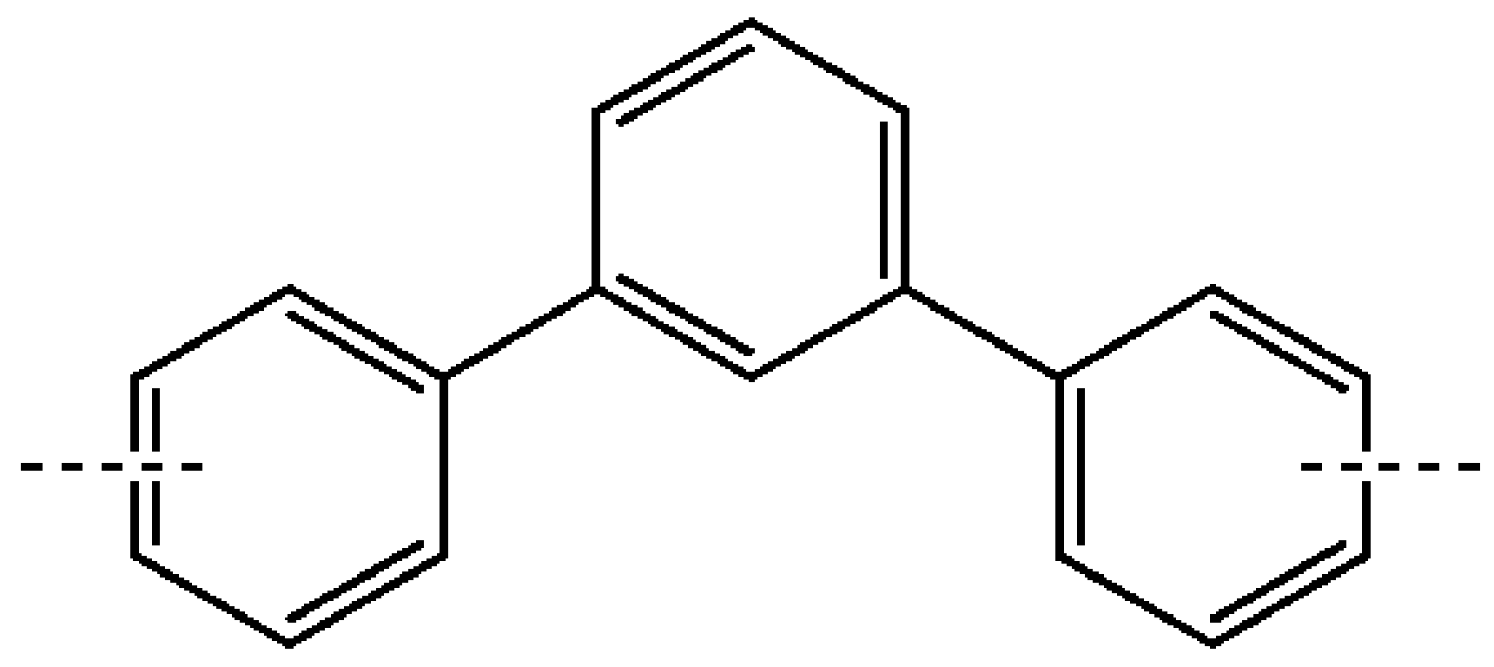


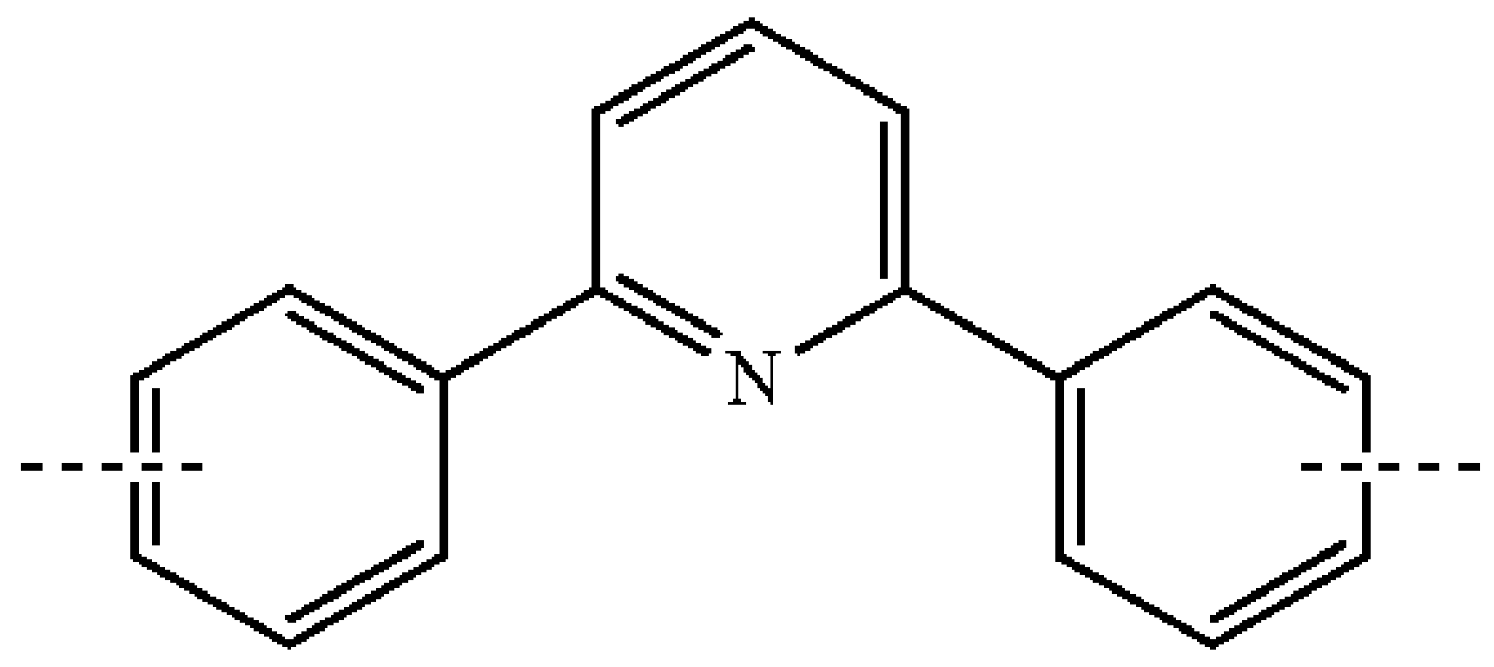


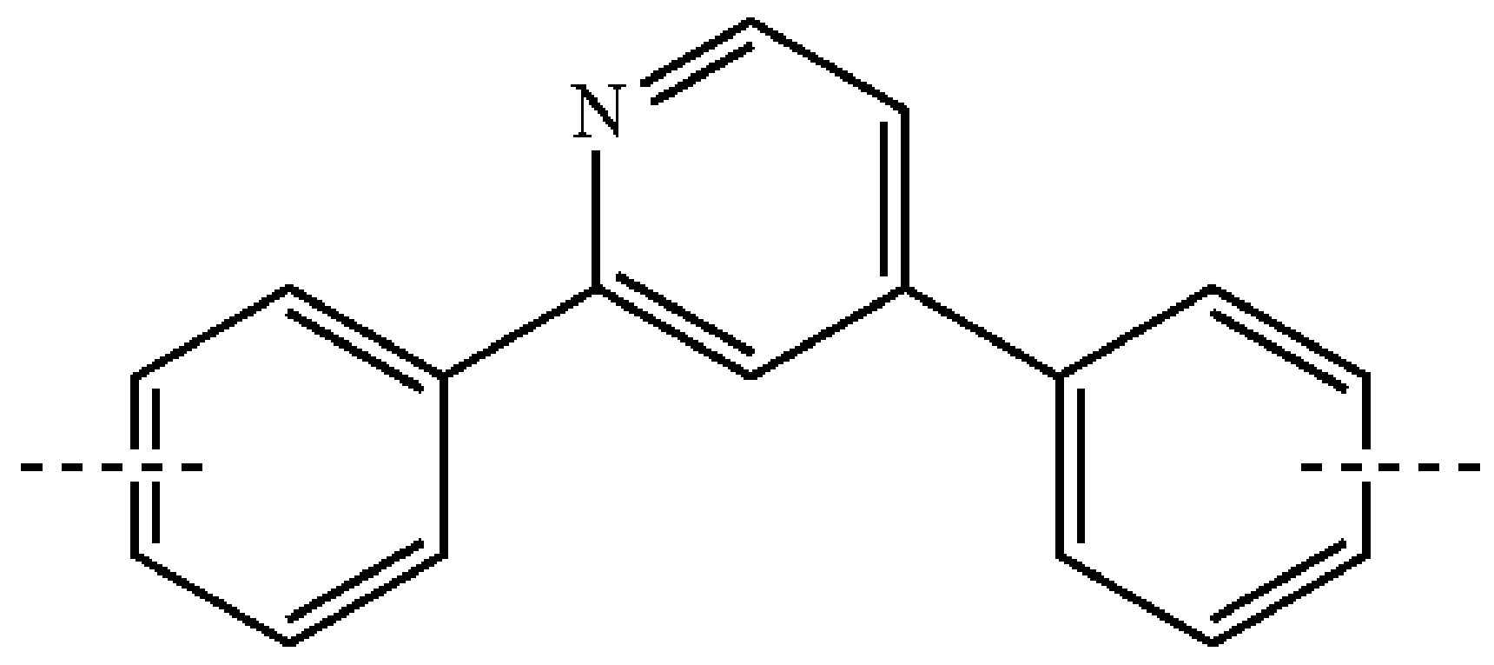


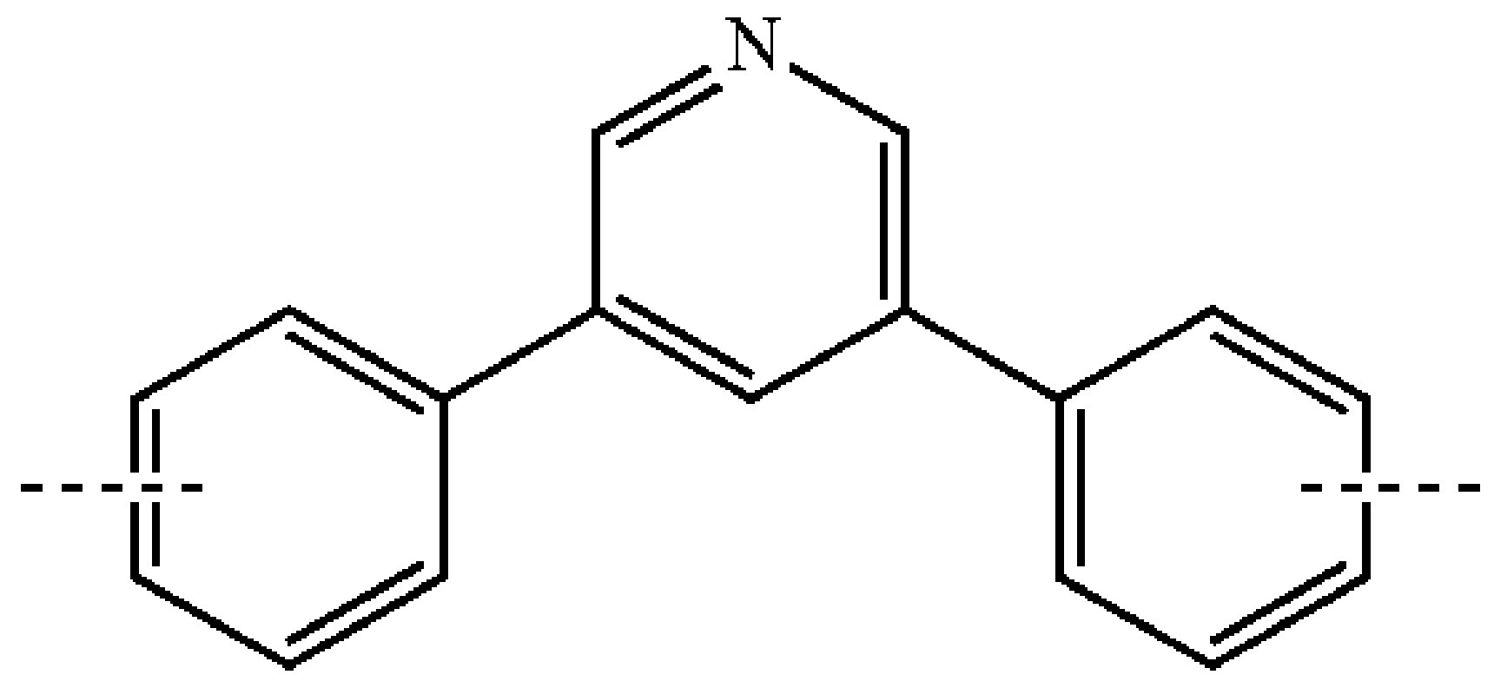


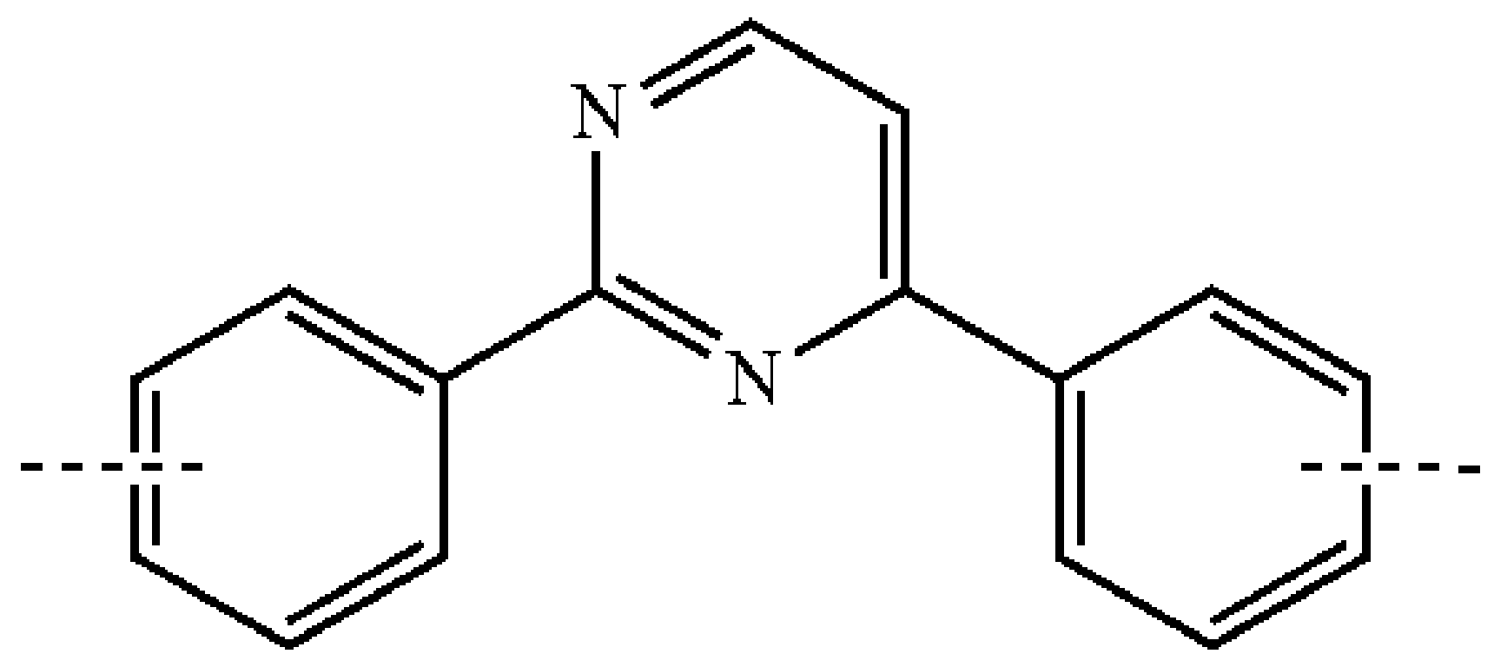


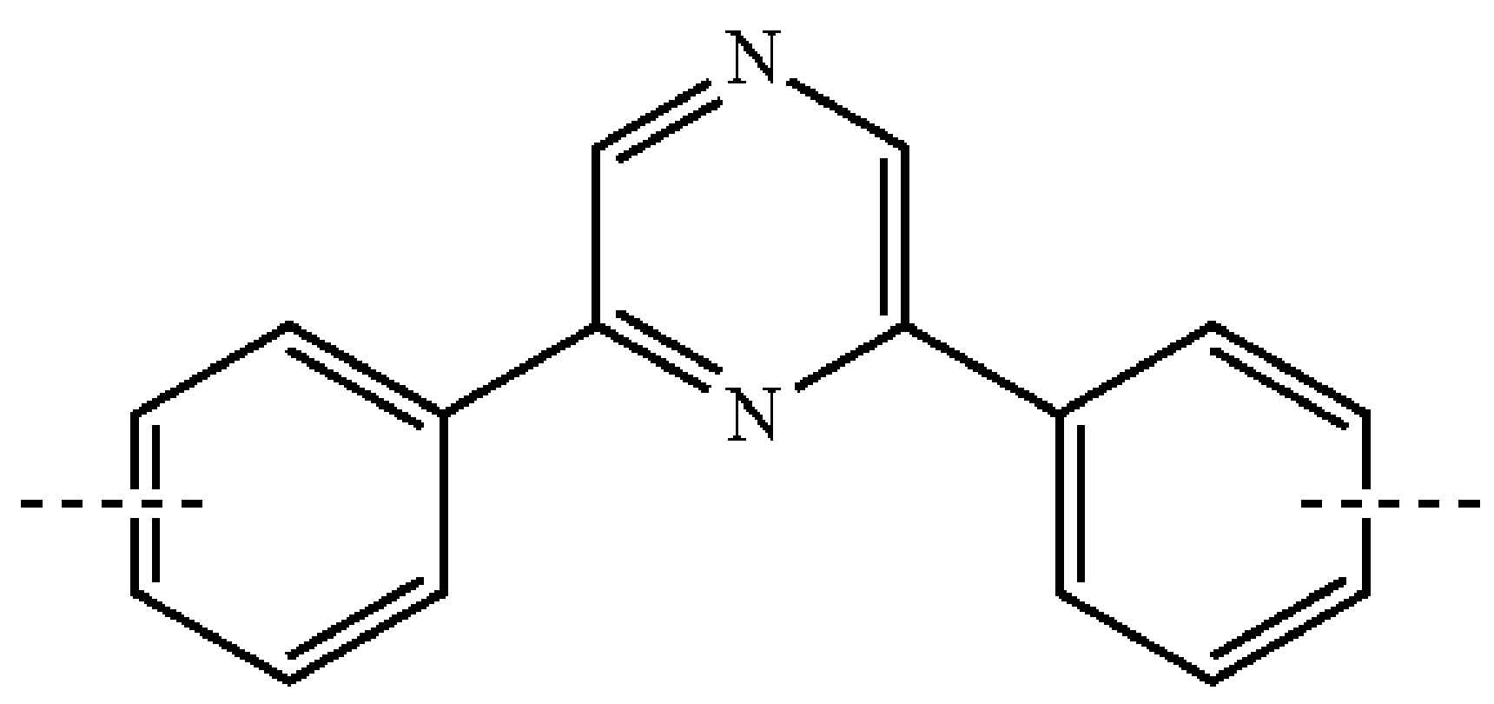












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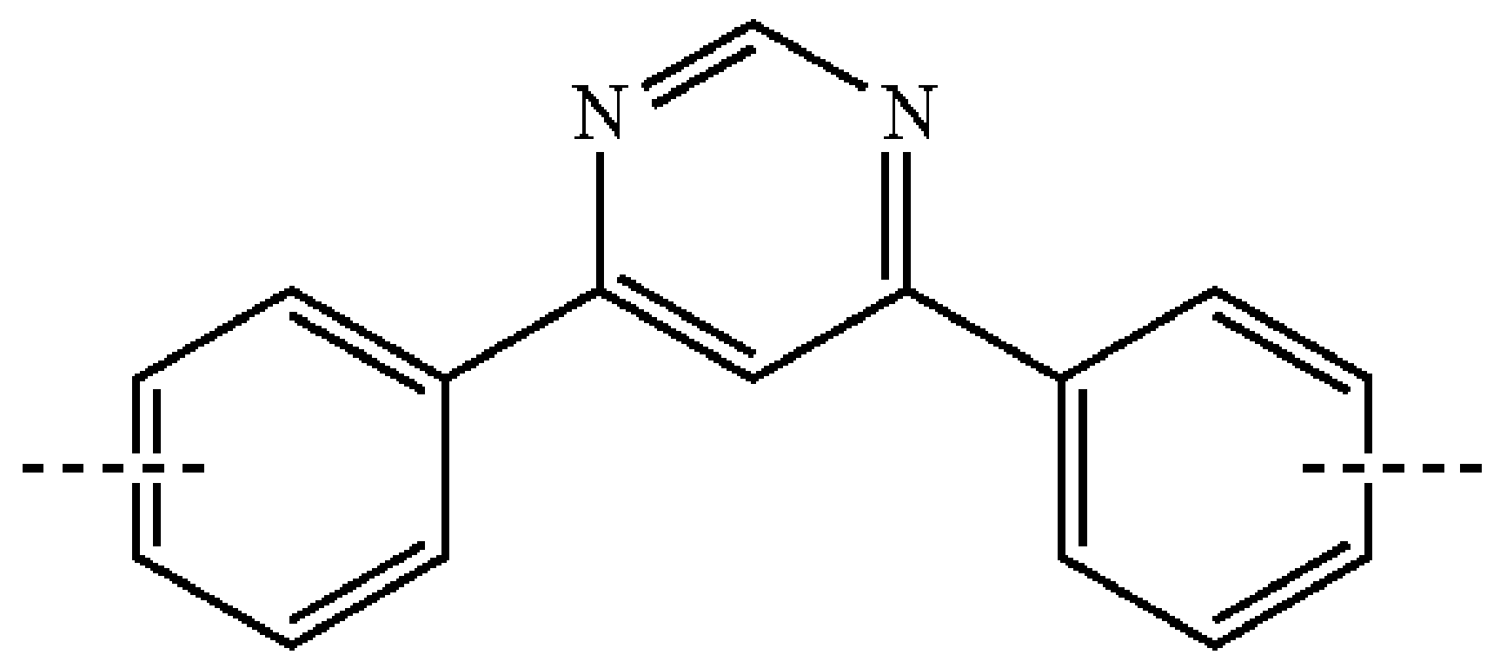
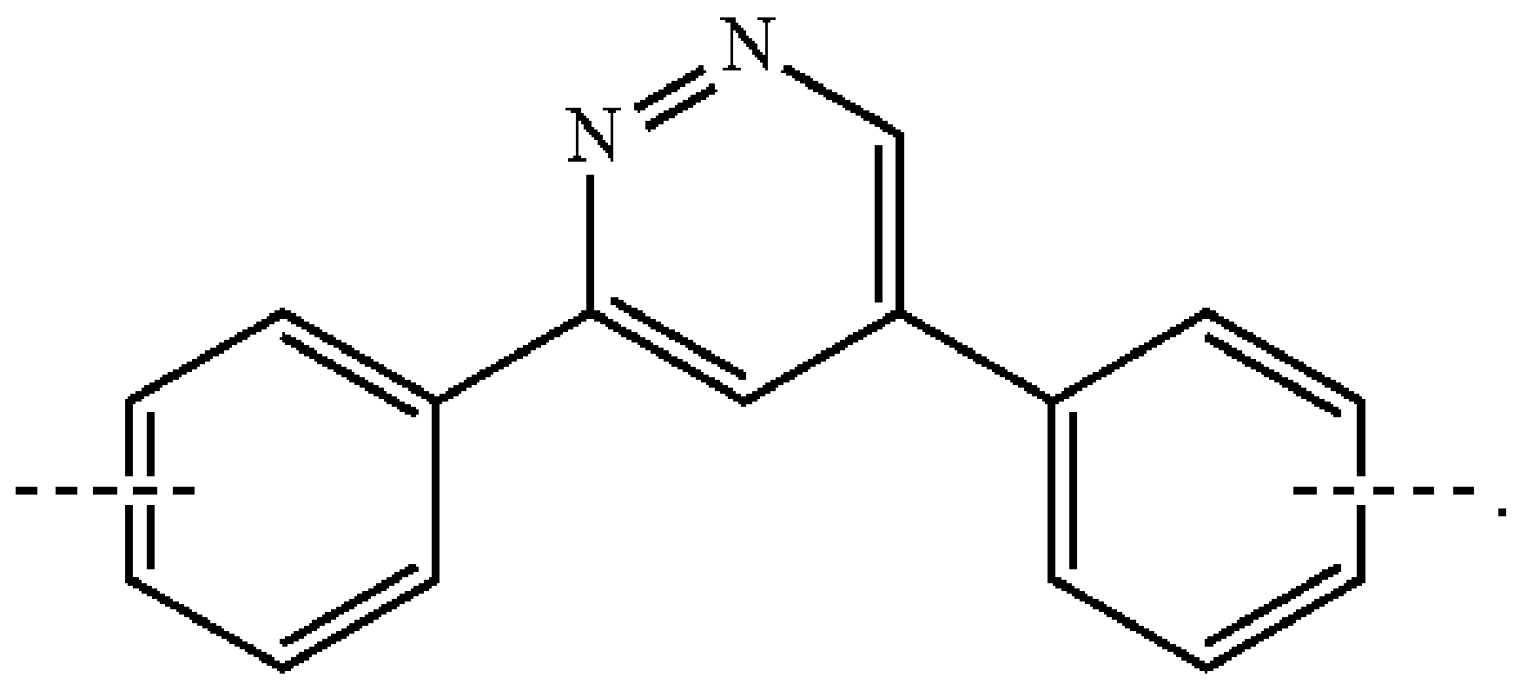


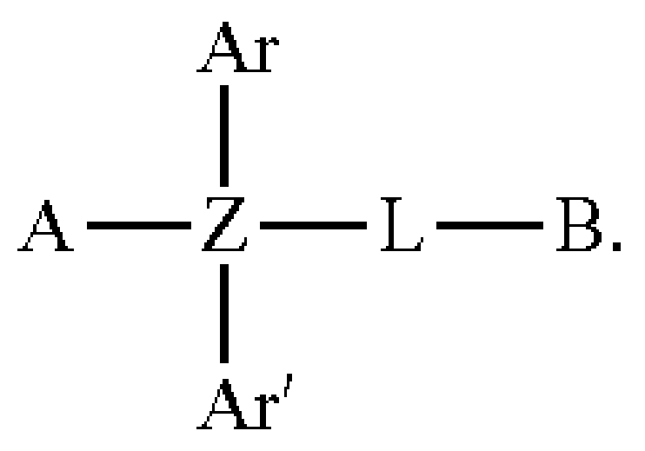


In one aspect, A is tripheynylene. In another aspect, A is pyrene. In one aspect, Ar and Ar' are phenyl. In one aspect, L is phenyl.

In one aspect, the compound is selected from the group consisting of Compound 1-Compound 35.

In one aspect, a first device is provided. The first device comprises an organic light-emitting device, which further comprises an anode, a cathode, and an organic layer, disposed between the anode and the cathode, comprising a compound having the Formula I:

Formula I



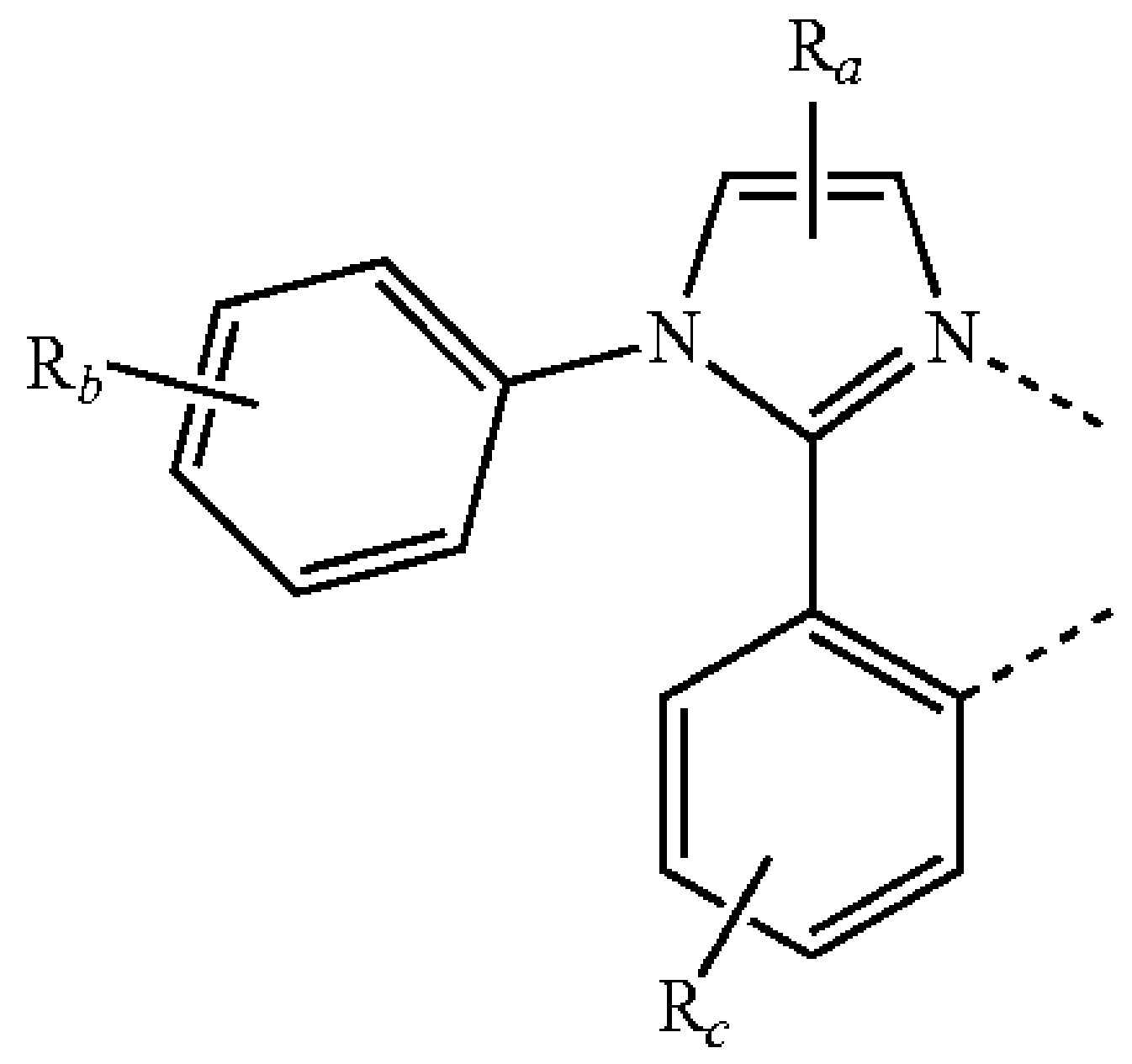
$$A—\underset{Ar'}{\overset{Ar}{Z}}—L—B.$$

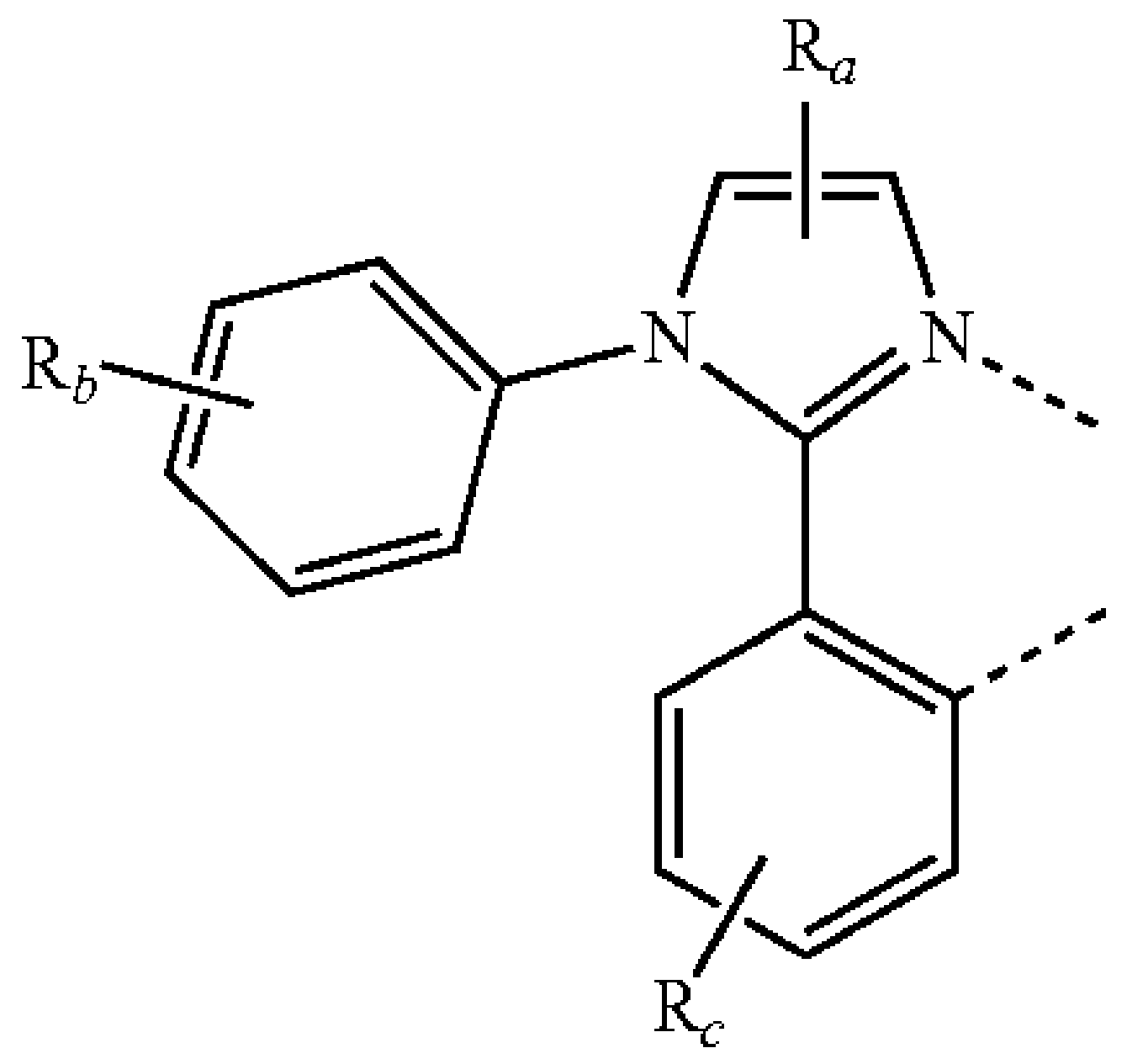
In the compound of Formula I, Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, naphthalene, dibenzothiophene and dibenzofuran, which are optionally further substituted. Z is selected from Si and Ge. L is a single bond or comprises an aryl or heteroaryl group having from 5-20 carbon atoms, which is optionally further substituted. A is a group directly bonded to Z and is selected from the group consisting of triphenylene, tetraphenylene, pyrene, naphthalene, fluoranthene, chrysene, phenanthrene, azatriphenylene, azatetraphenylene, azapyrene, azanaphthalene, azafluoranthene, azachrysene, azaphenanthrene, and combinations thereof, which are optionally further substituted with one or more groups selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof.

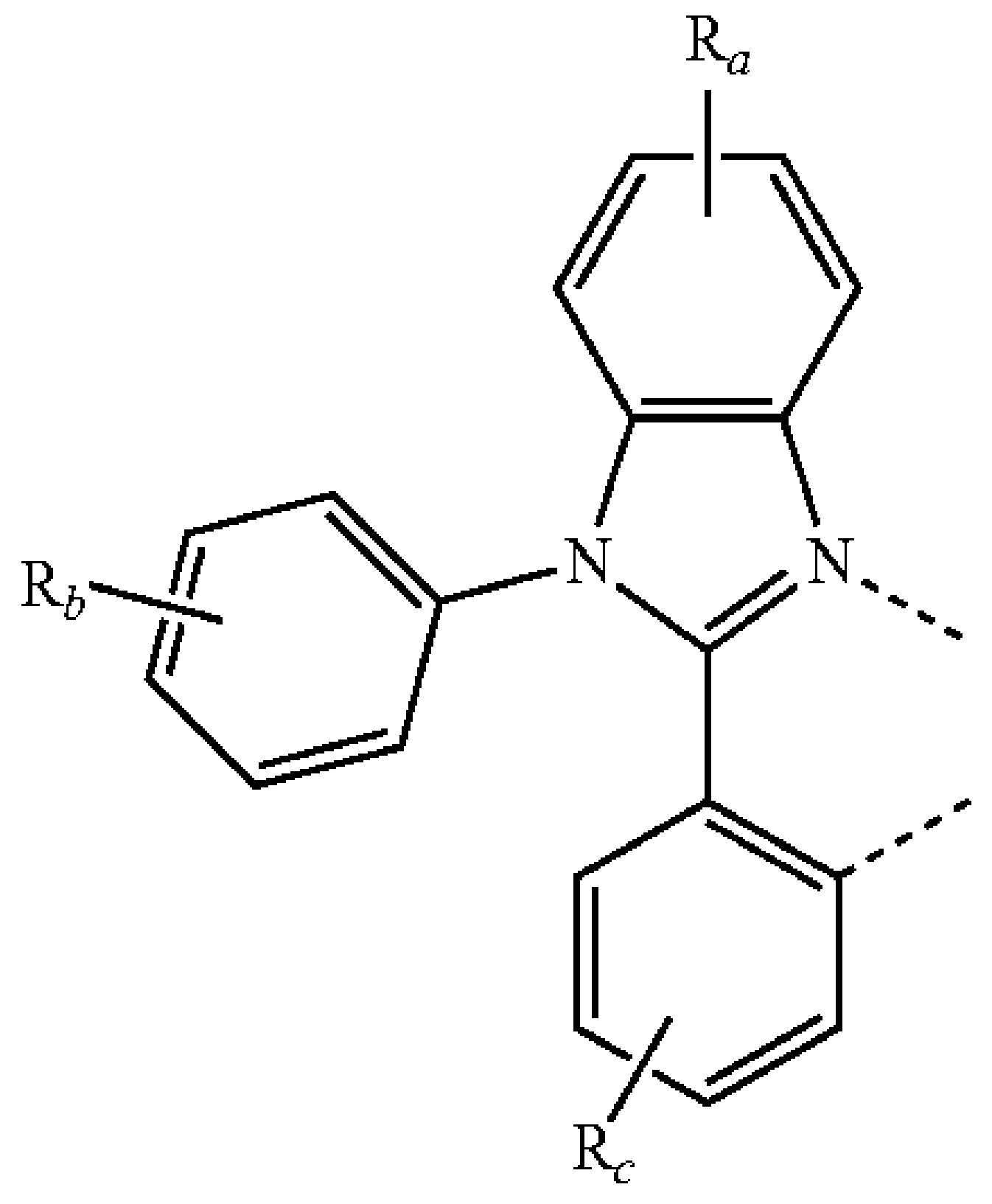
B contains a group selected from the group consisting of carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene, azadibenzoselenophene, and combinations thereof, which are optionally further substituted with one or more groups selected from hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein the substitution is optionally fused to the carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene or azadibenzoselenophene group.

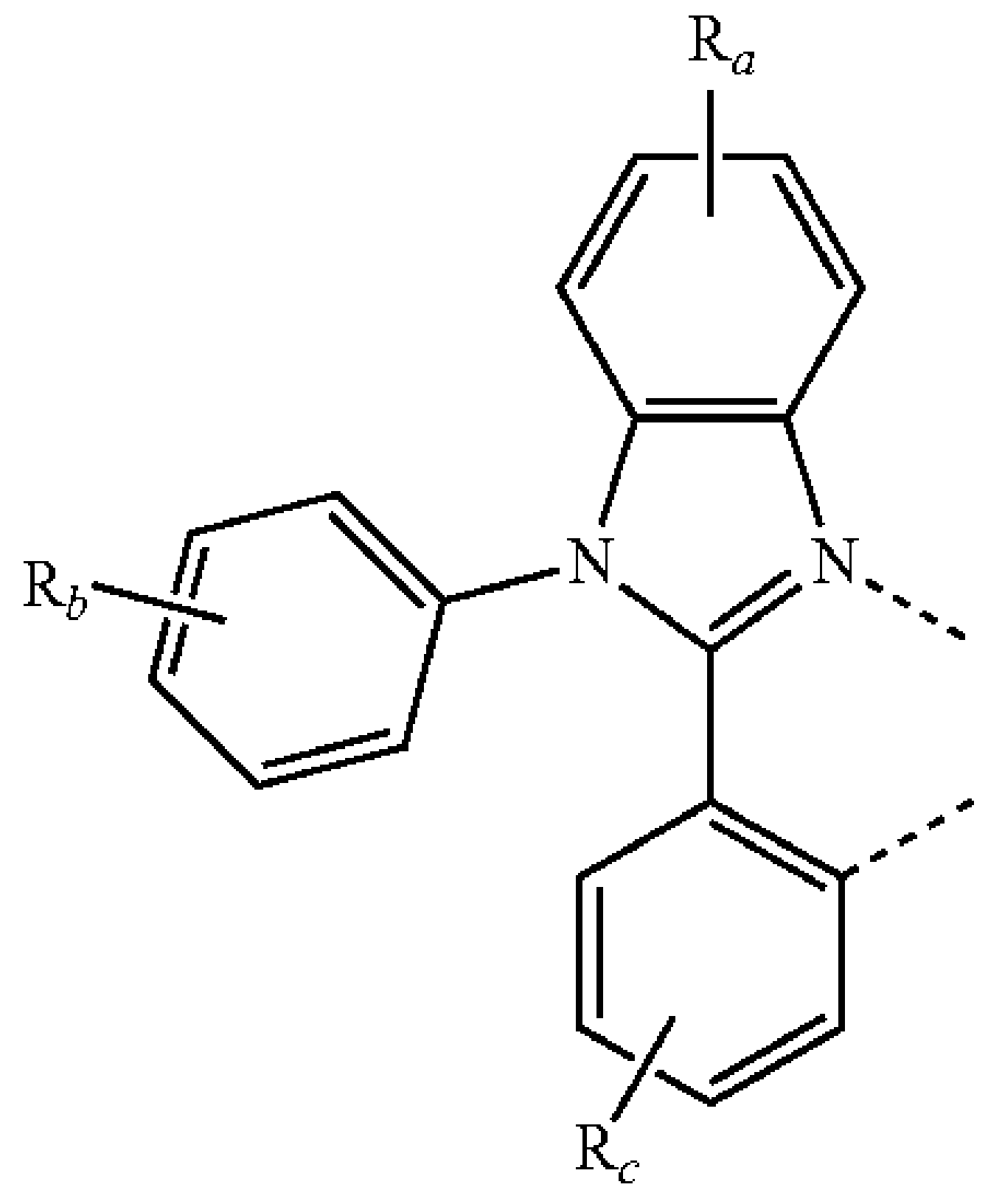
In one aspect, the organic layer is an emissive layer and the compound of Formula I is a host. In another aspect, the organic layer further comprises an emissive dopant.

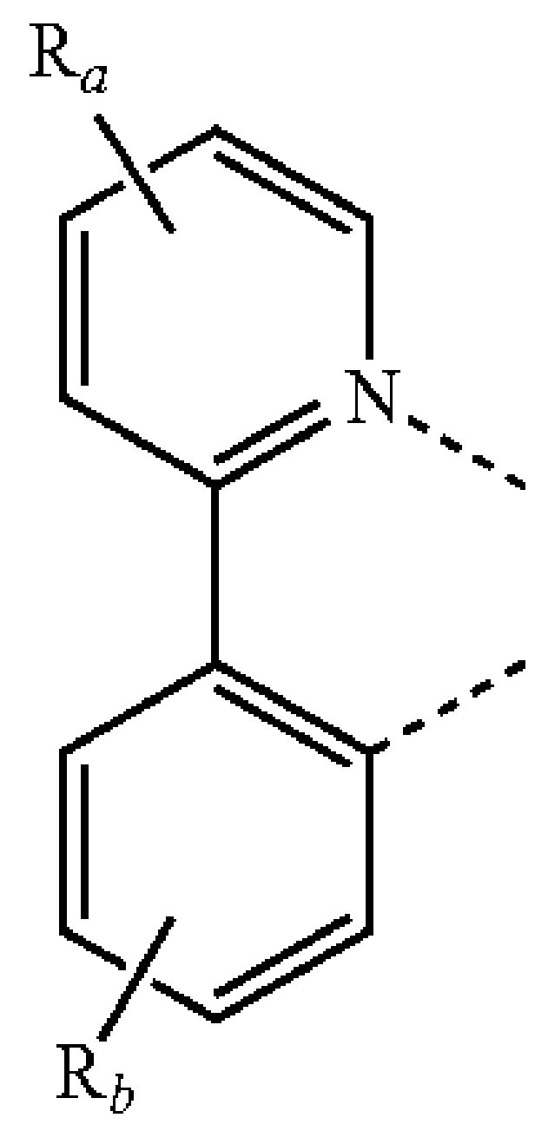
In one aspect, the emissive dopant is a transition metal complex having at least one ligand selected from the group consisting of:

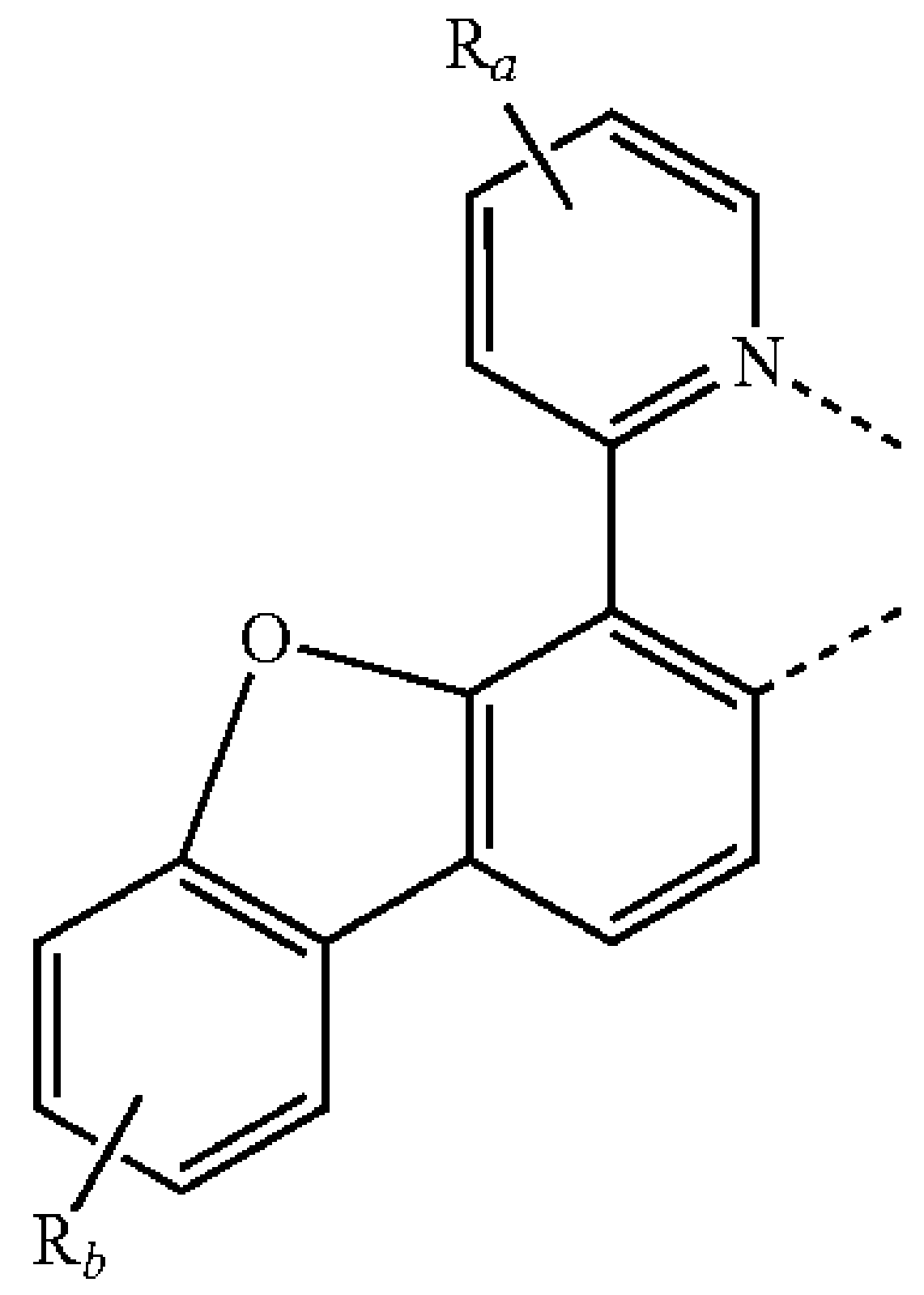


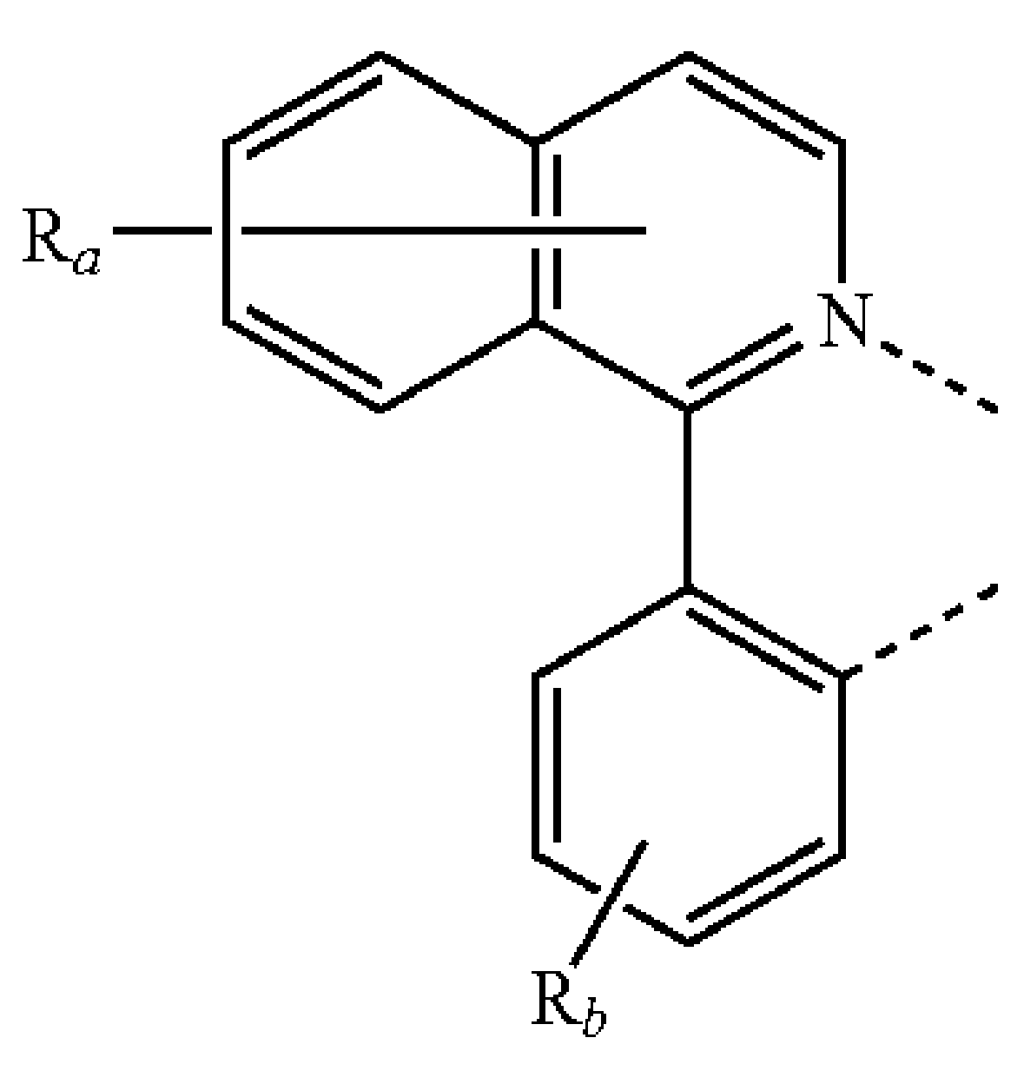


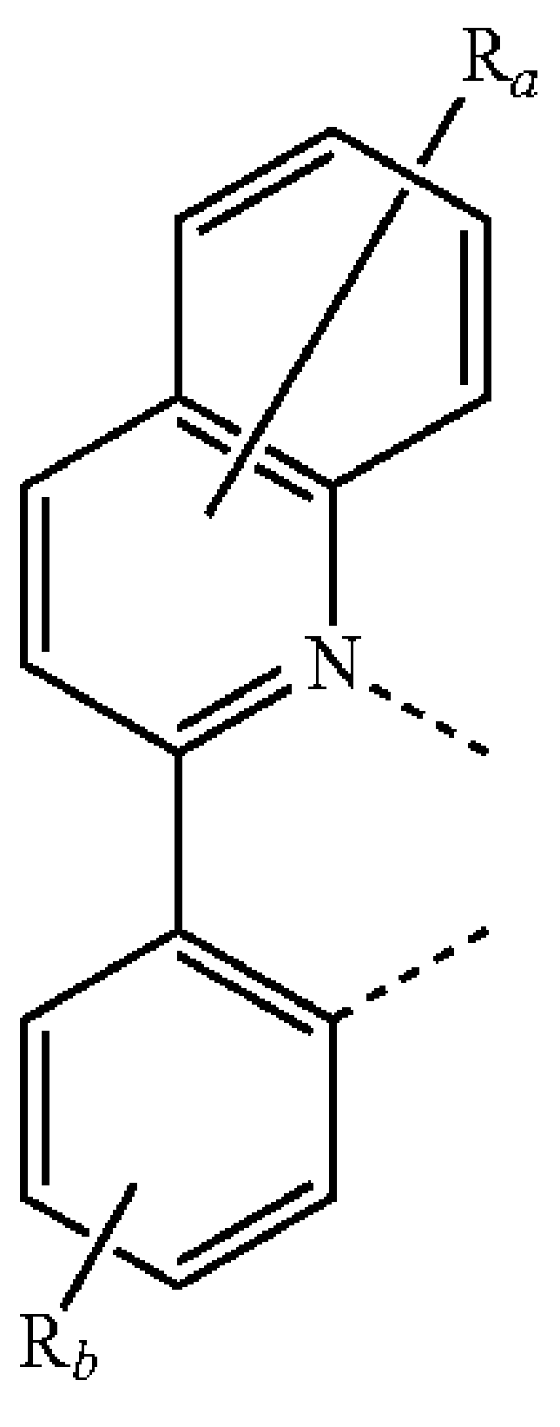


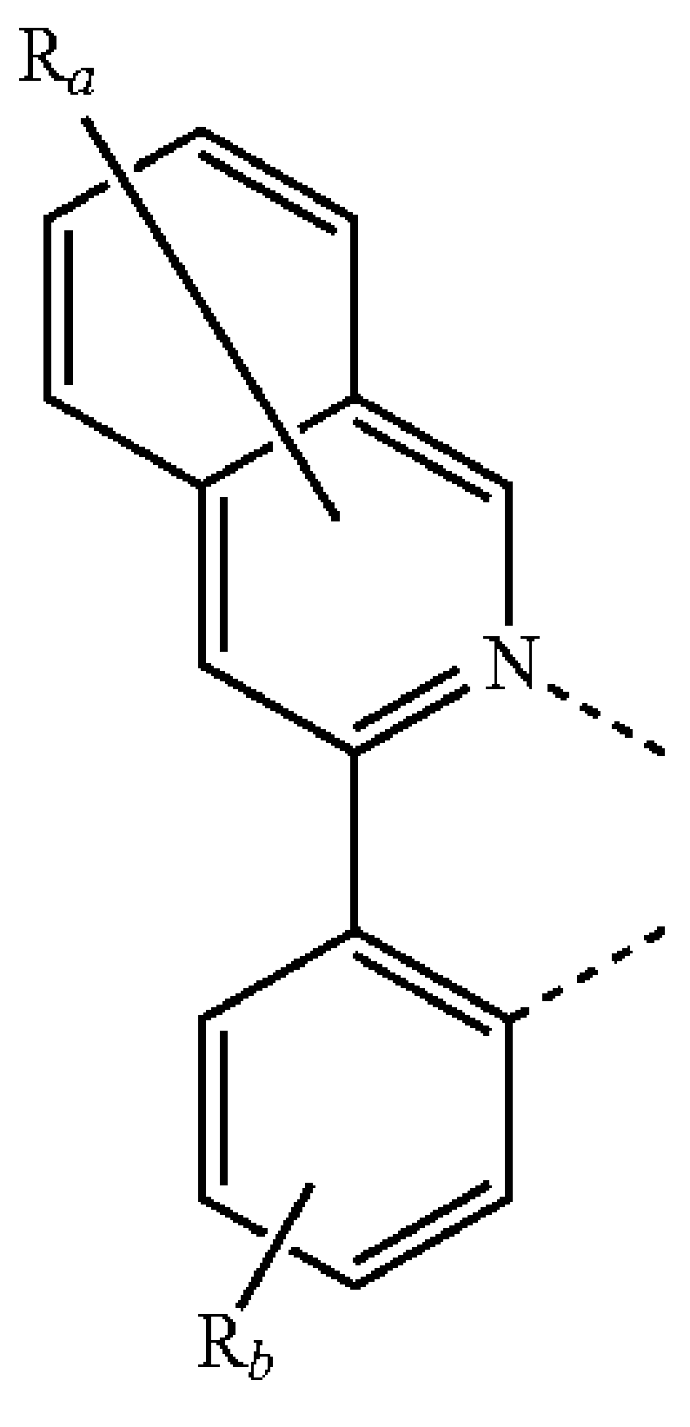


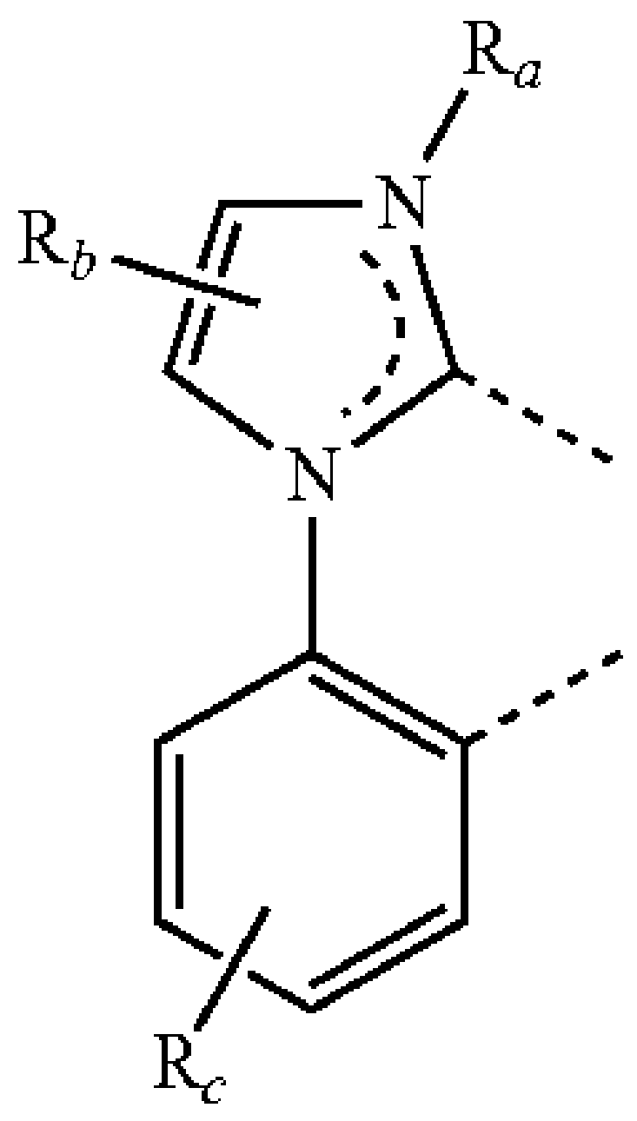


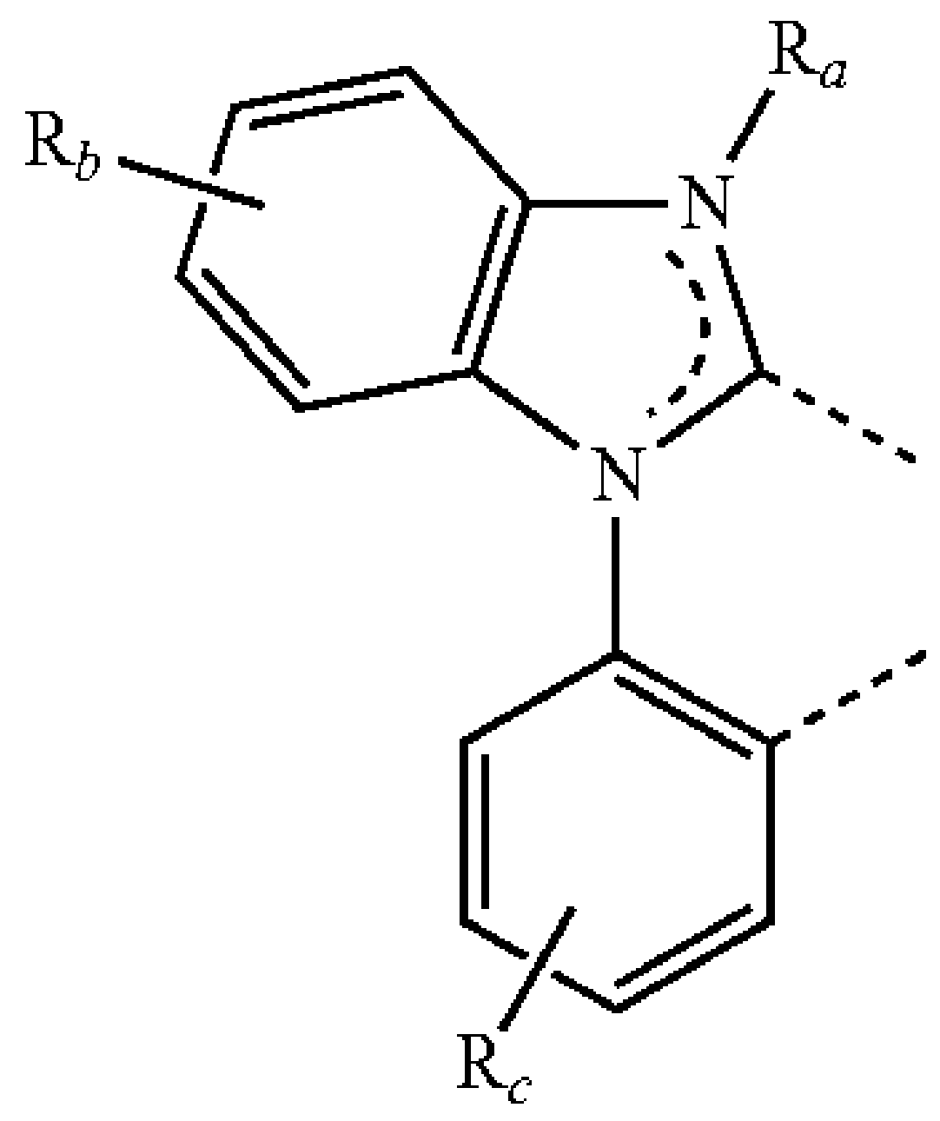












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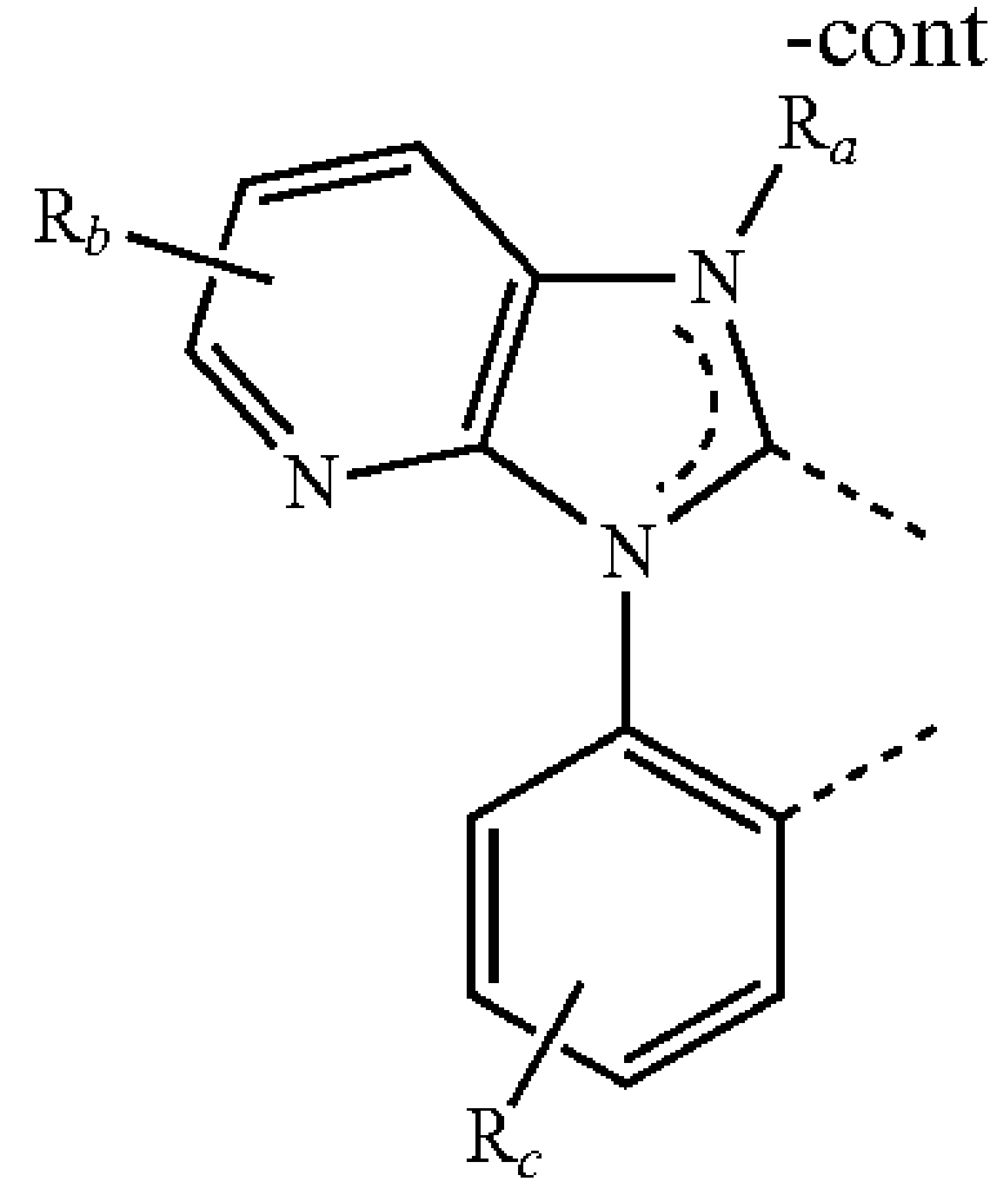
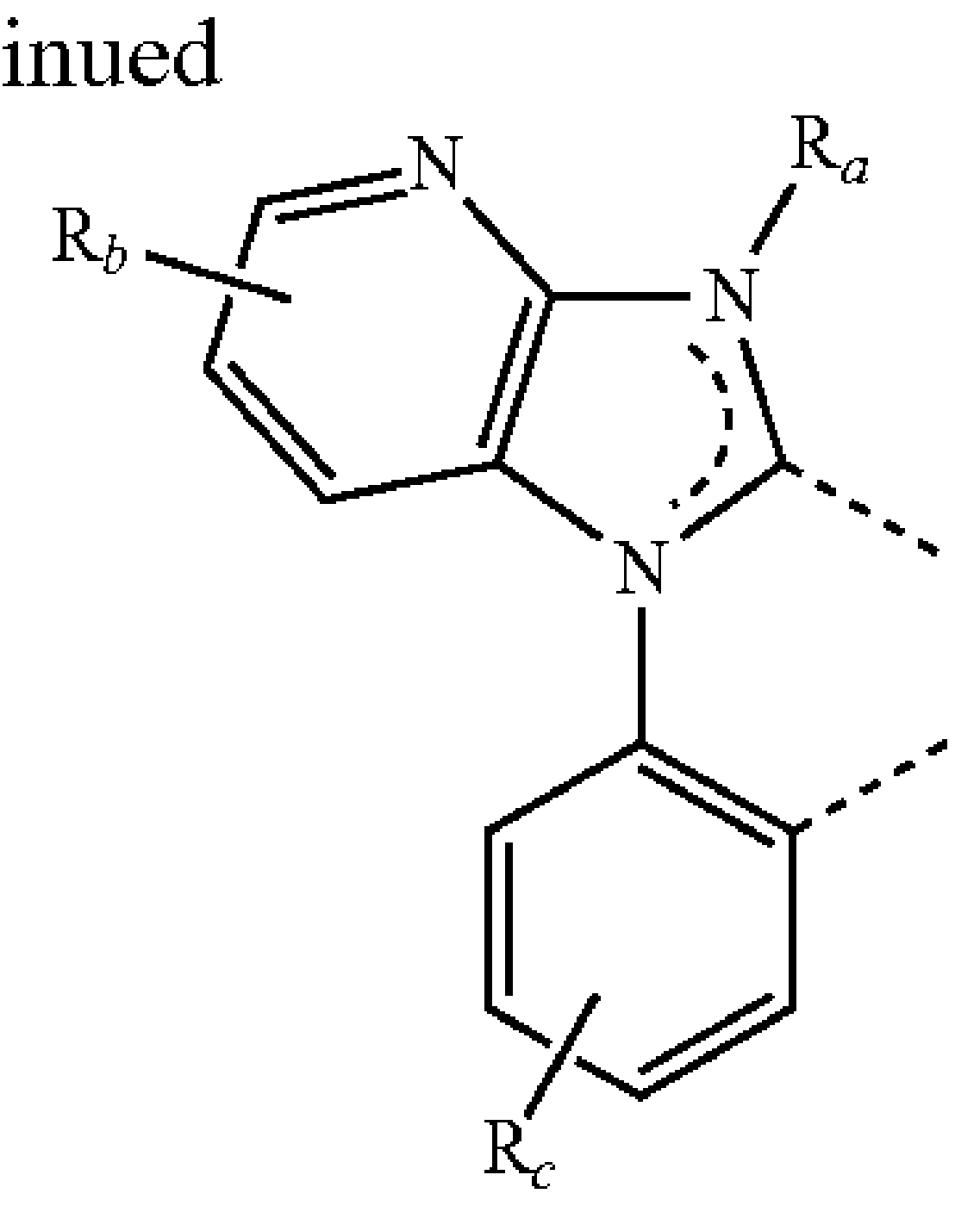
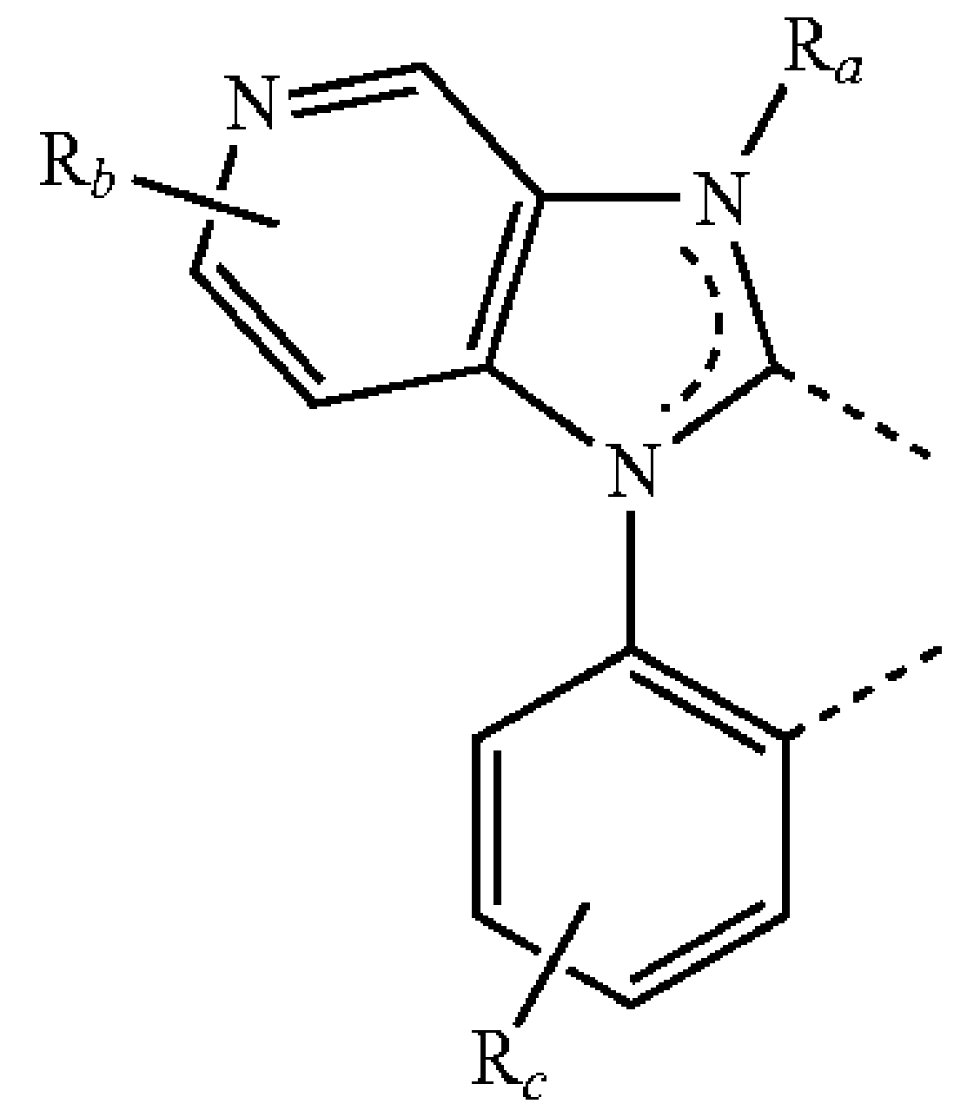
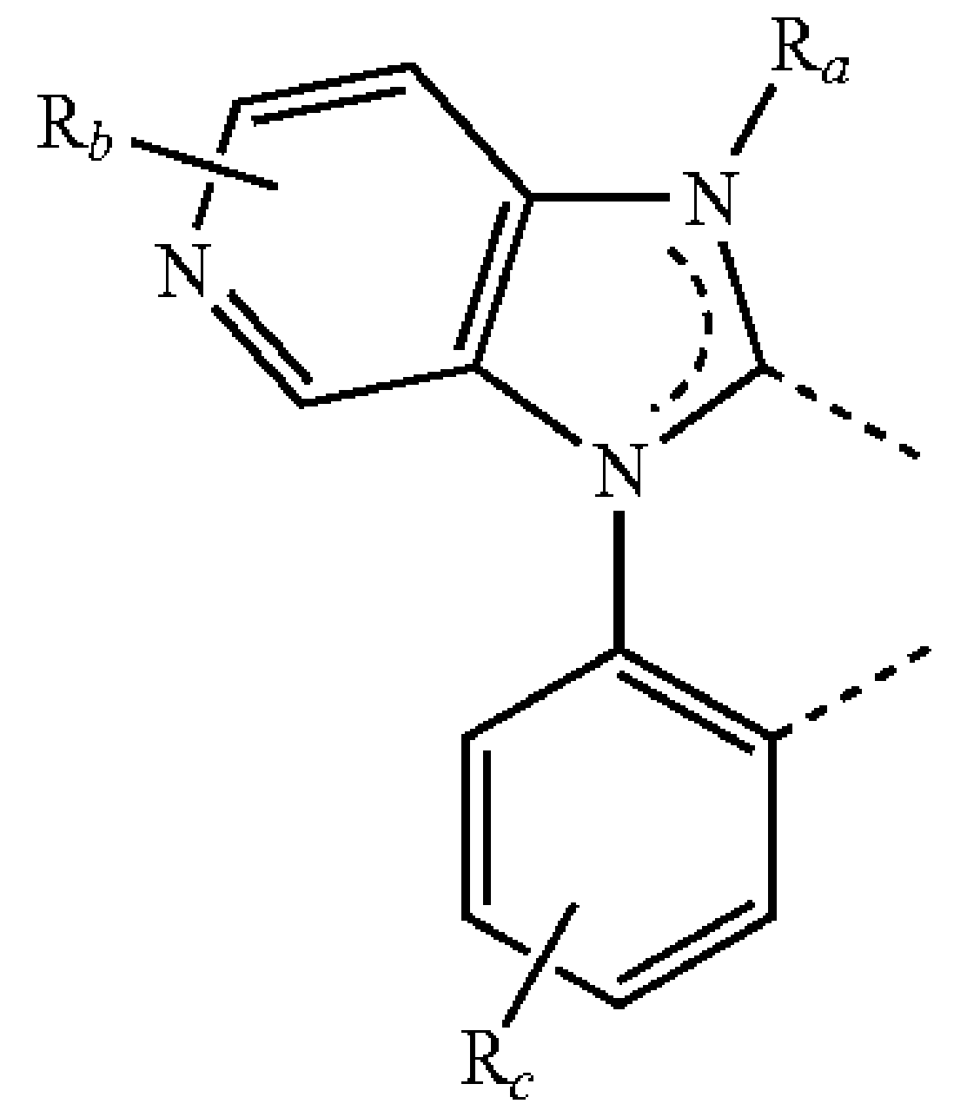
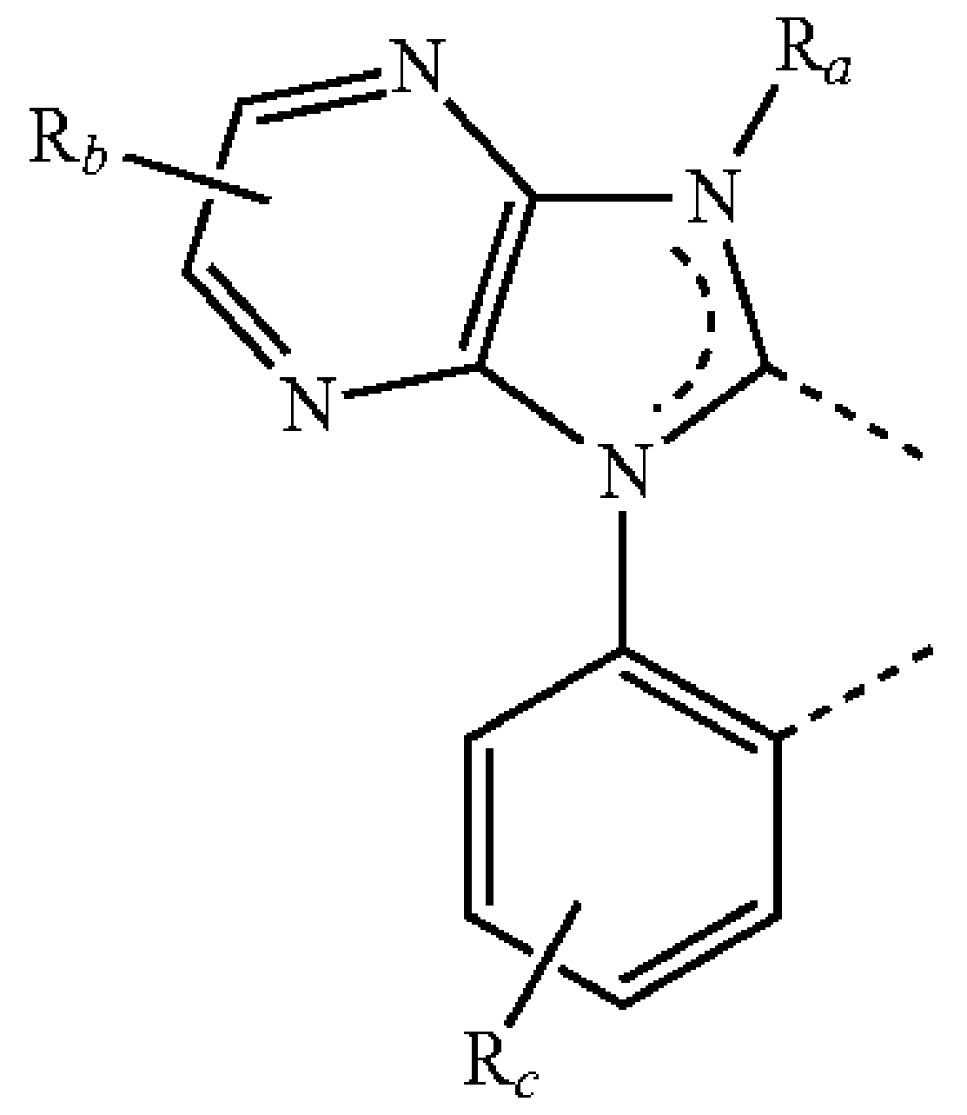
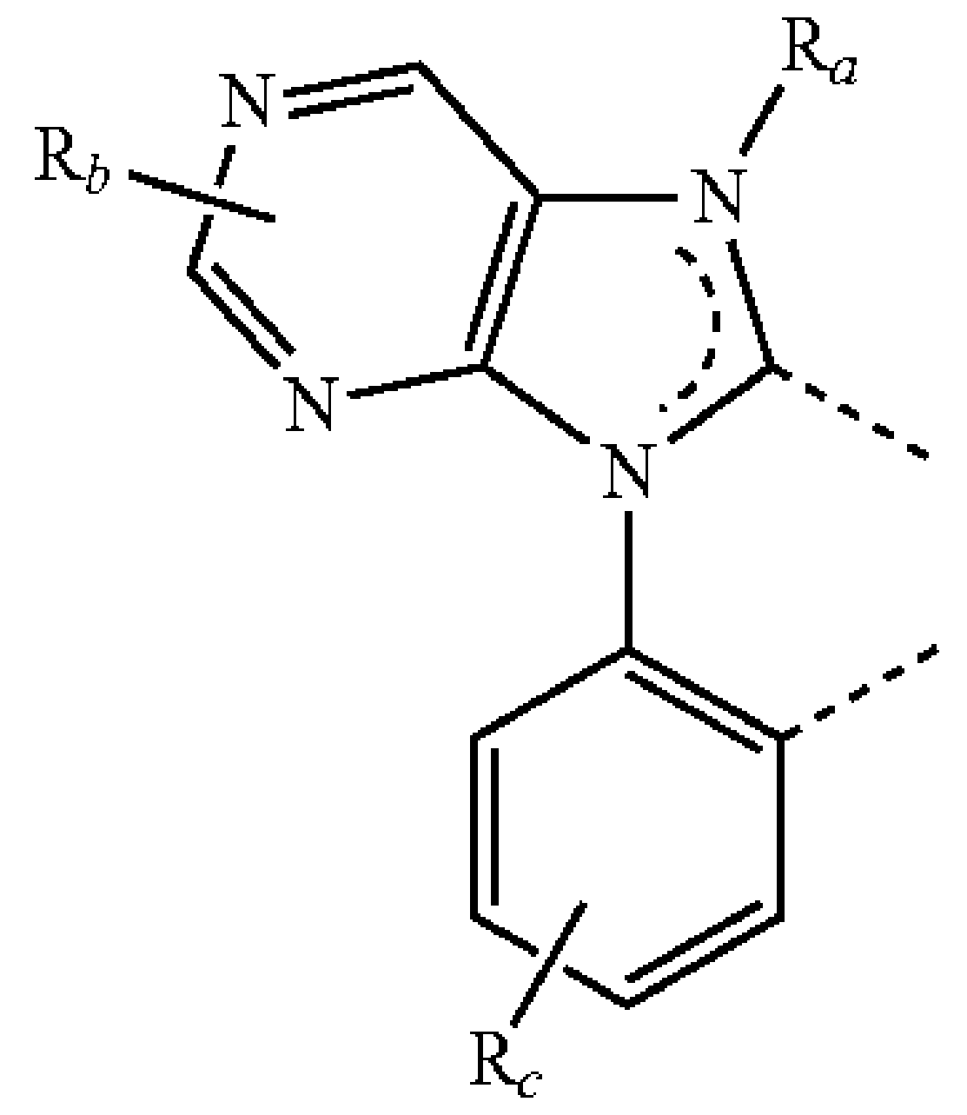


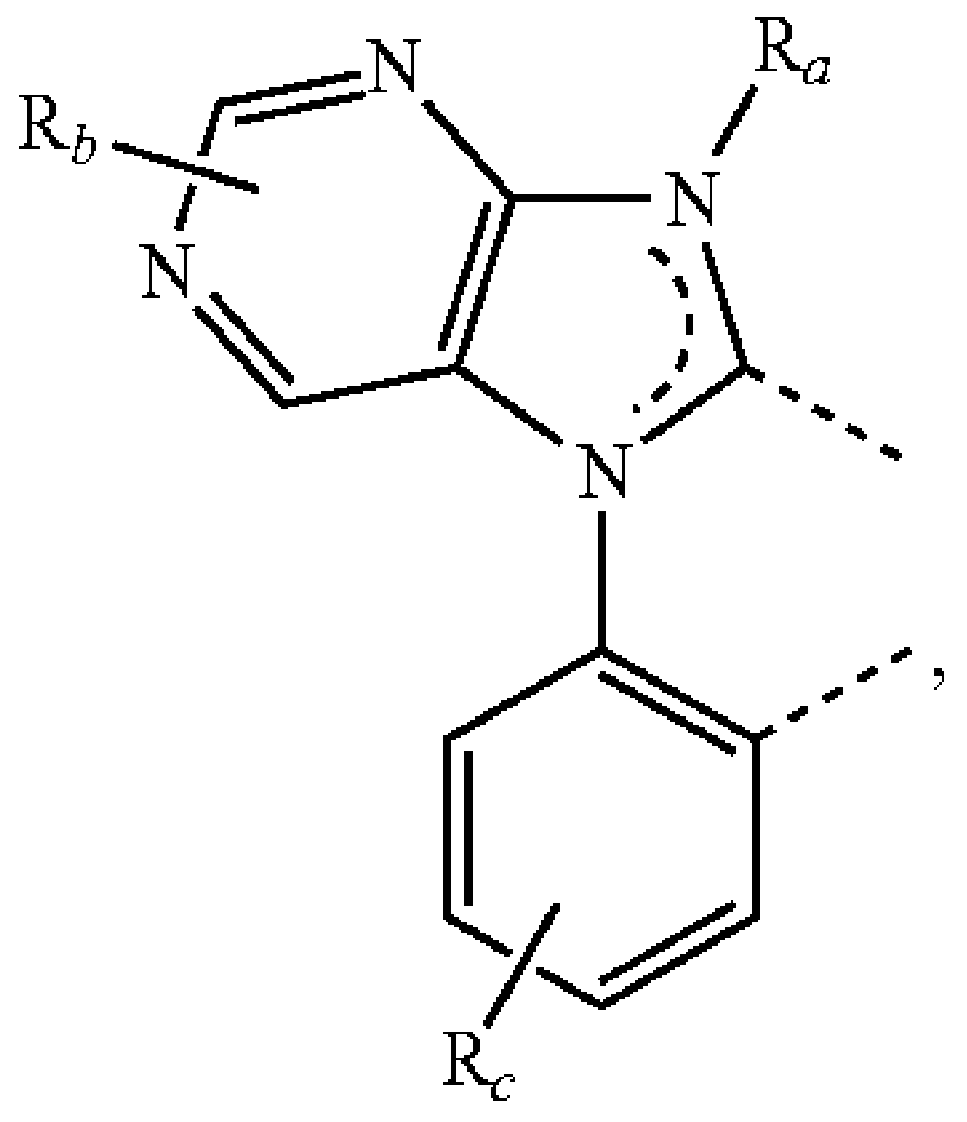






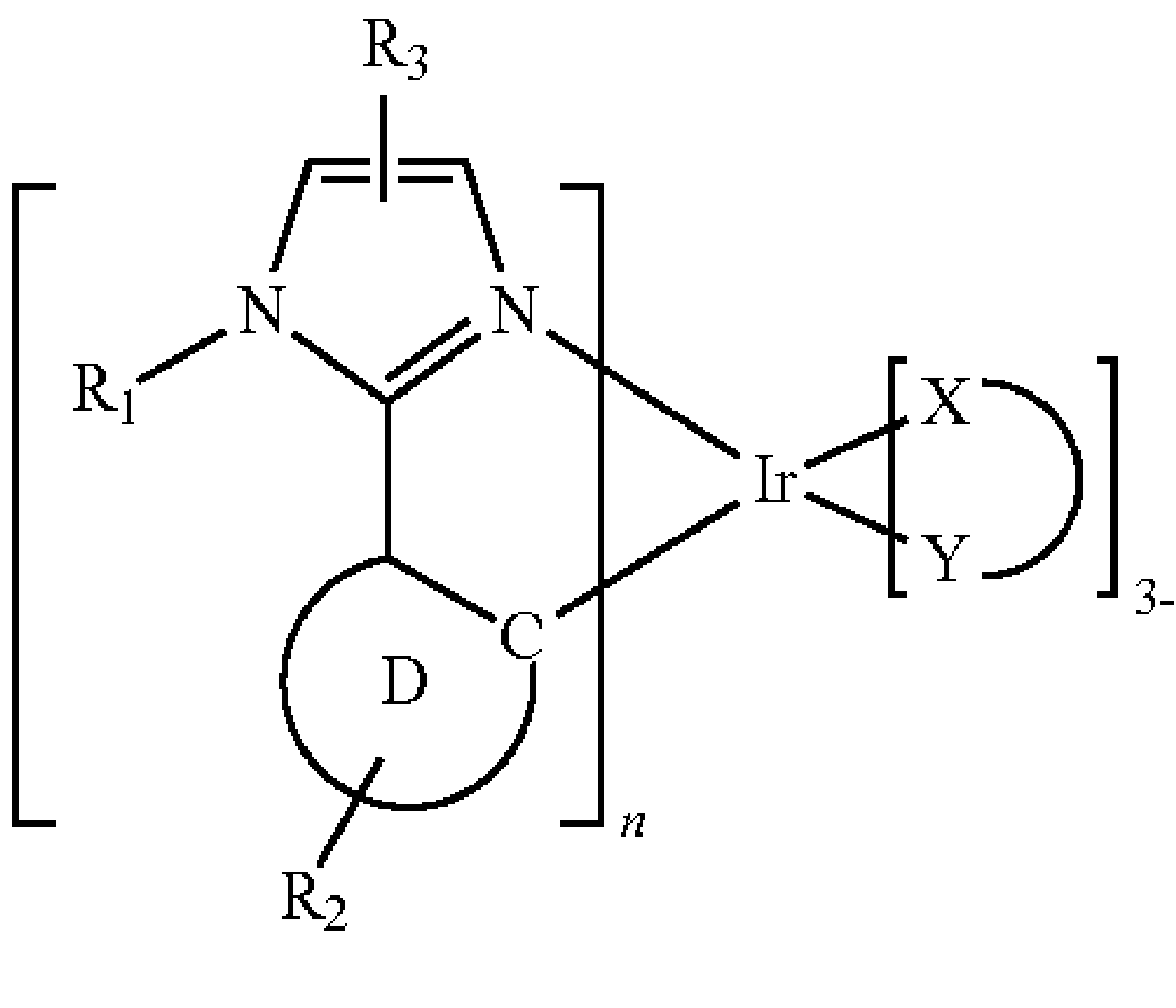






wherein R_a, R_b, and R_c may represent mono, di, tri or tetra substitutions, wherein R_a, R_b, and R_c are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and wherein two adjacent substituents of R_a, R_b, and R_c are optionally joined to form a fused ring.

In one aspect, the emissive dopant has the formula



wherein D is a 5- or 6-membered carbocyclic or heterocyclic ring, wherein R_1, R_2, and R_3 independently represent mono, di, tri or tetra substitution, wherein each of R_1, R_2, and R_3 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, wherein R_1 can be optionally linked to ring D, wherein n is 1, 2, or 3, and wherein X—Y is another ligand.

In one aspect, the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer.

In another aspect, the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer. In one aspect, the second organic layer is an electron transporting layer and the compound having the Formula I is an electron transporting material in the second organic layer.

In one aspect, the first device is a consumer product. In another aspect, the first device is an organic light-emitting device. In one aspect, the first device comprises a lighting panel.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows an organic light emitting device.

FIG. **2** shows an inverted organic light emitting device that does not have a separate electron transport layer.

FIG. **3** shows a compound of Formula I.

FIG. **4** shows an example device that incorporates compounds of Formula I.

FIG. **5** shows the differential scanning calorimetry scans for selected compounds of Formula I and for selected comparative compounds.

DETAILED DESCRIPTION

Generally, an OLED comprises at least one organic layer disposed between and electrically connected to an anode and a cathode. When a current is applied, the anode injects holes and the cathode injects electrons into the organic layer(s). The injected holes and electrons each migrate toward the oppositely charged electrode. When an electron and hole localize on the same molecule, an "exciton," which is a localized electron-hole pair having an excited energy state, is formed. Light is emitted when the exciton relaxes via a photoemissive mechanism. In some cases, the exciton may be localized on an excimer or an exciplex. Non-radiative mechanisms, such as thermal relaxation, may also occur, but are generally considered undesirable.

The initial OLEDs used emissive molecules that emitted light from their singlet states ("fluorescence") as disclosed, for example, in U.S. Pat. No. 4,769,292, which is incorporated by reference in its entirety. Fluorescent emission generally occurs in a time frame of less than 10 nanoseconds.

More recently, OLEDs having emissive materials that emit light from triplet states ("phosphorescence") have been demonstrated. Baldo et al., "Highly Efficient Phosphorescent Emission from Organic Electroluminescent Devices," Nature, vol. 395, 151-154, 1998; ("Baldo-I") and Baldo et al., "Very high-efficiency green organic light-emitting devices based on electrophosphorescence," Appl. Phys. Lett., vol. 75, No. 3, 4-6 (1999) ("Baldo-II"), which are incorporated by reference in their entireties. Phosphorescence is described in more detail in U.S. Pat. No. 7,279,704 at cols. 5-6, which are incorporated by reference.

FIG. **1** shows an organic light emitting device **100**. The figures are not necessarily drawn to scale. Device **100** may include a substrate **110**, an anode **115**, a hole injection layer **120**, a hole transport layer **125**, an electron blocking layer **130**, an emissive layer **135**, a hole blocking layer **140**, an electron transport layer **145**, an electron injection layer **150**, a protective layer **155**, and a cathode **160**. Cathode **160** is a compound cathode having a first conductive layer **162** and a second conductive layer **164**. Device **100** may be fabricated by depositing the layers described, in order. The properties and functions of these various layers, as well as example materials, are described in more detail in U.S. Pat. No. 7,279,704 at cols. 6-10, which are incorporated by reference.

More examples for each of these layers are available. For example, a flexible and transparent substrate-anode combination is disclosed in U.S. Pat. No. 5,844,363, which is incorporated by reference in its entirety. An example of a p-doped hole transport layer is m-MTDATA doped with F.sub.4-TCNQ at a molar ratio of 50:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. Examples of emissive and host materials are disclosed in U.S. Pat. No. 6,303,238 to Thompson et al., which is incorporated by reference in its entirety. An example of an n-doped electron transport layer is BPhen doped with Li at a molar ratio of 1:1, as disclosed in U.S. Patent Application Publication No. 2003/0230980, which is incorporated by reference in its entirety. U.S. Pat. Nos. 5,703,436 and 5,707,745, which are incorporated by reference in their entireties, disclose examples of cathodes including compound cathodes having a thin layer of metal such as Mg:Ag with an overlying transparent, electrically-conductive, sputter-deposited ITO layer. The theory and use of blocking layers is described in more detail in U.S. Pat. No. 6,097,147 and U.S. Patent Application Publication No. 2003/0230980, which are incorporated by reference in their entireties. Examples of injection layers are provided in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety. A description of protective layers may be found in U.S. Patent Application Publication No. 2004/0174116, which is incorporated by reference in its entirety.

FIG. **2** shows an inverted OLED **200**. The device includes a substrate **210**, a cathode **215**, an emissive layer **220**, a hole transport layer **225**, and an anode **230**. Device **200** may be fabricated by depositing the layers described, in order. Because the most common OLED configuration has a cathode disposed over the anode, and device **200** has cathode **215** disposed under anode **230**, device **200** may be referred to as an "inverted" OLED. Materials similar to those described with respect to device **100** may be used in the corresponding layers of device **200**. FIG. **2** provides one example of how some layers may be omitted from the structure of device **100**.

The simple layered structure illustrated in FIGS. **1** and **2** is provided by way of non-limiting example, and it is understood that embodiments of the invention may be used in connection with a wide variety of other structures. The specific materials and structures described are exemplary in nature, and other materials and structures may be used. Functional OLEDs may be achieved by combining the various layers described in different ways, or layers may be omitted entirely, based on design, performance, and cost factors. Other layers not specifically described may also be included. Materials other than those specifically described may be used. Although many of the examples provided herein describe various layers as comprising a single material, it is understood that combinations of materials, such as a mixture of host and dopant, or more generally a mixture, may be used. Also, the layers may have various sublayers. The names given to the various layers herein are not intended to be strictly limiting. For example, in device **200**, hole transport layer **225** transports holes and injects holes into emissive layer **220**, and may be described as a hole transport layer or a hole injection layer. In one embodiment, an OLED may be described as having an "organic layer" disposed between a cathode and an anode. This organic layer may comprise a single layer, or may further comprise multiple layers of different organic materials as described, for example, with respect to FIGS. **1** and **2**.

Structures and materials not specifically described may also be used, such as OLEDs comprised of polymeric materials (PLEDs) such as disclosed in U.S. Pat. No. 5,247,190 to Friend et al., which is incorporated by reference in its entirety. By way of further example, OLEDs having a single organic layer may be used. OLEDs may be stacked, for example as described in U.S. Pat. No. 5,707,745 to Forrest et al, which is incorporated by reference in its entirety. The OLED structure may deviate from the simple layered structure illustrated in FIGS. **1** and **2**. For example, the substrate may include an angled reflective surface to improve out-coupling, such as a mesa structure as described in U.S. Pat. No. 6,091,195 to Forrest et al., and/or a pit structure as described in U.S. Pat. No. 5,834,893 to Bulovic et al., which are incorporated by reference in their entireties.

Unless otherwise specified, any of the layers of the various embodiments may be deposited by any suitable method. For the organic layers, preferred methods include thermal evaporation, ink-jet, such as described in U.S. Pat. Nos. 6,013,982 and 6,087,196, which are incorporated by reference in their entireties, organic vapor phase deposition (OVPD), such as described in U.S. Pat. No. 6,337,102 to Forrest et al., which is incorporated by reference in its entirety, and deposition by organic vapor jet printing (OVJP), such as described in U.S. patent application Ser. No. 10/233,470, which is incorporated by reference in its entirety. Other suitable deposition methods include spin coating and other solution based processes. Solution based processes are preferably carried out in nitrogen or an inert atmosphere. For the other layers, preferred methods include thermal evaporation. Preferred patterning methods include deposition through a mask, cold welding such as described in U.S. Pat. Nos. 6,294,398 and 6,468,819, which are incorporated by reference in their entireties, and patterning associated with some of the deposition methods such as ink-jet and OVJD. Other methods may also be used. The materials to be deposited may be modified to make them compatible with a particular deposition method. For example, substituents such as alkyl and aryl groups, branched or unbranched, and preferably containing at least 3 carbons, may be used in small molecules to enhance their ability to undergo solution processing. Substituents having 20 carbons or more may be used, and 3-20 carbons is a preferred range. Materials with asymmetric structures may have better solution processability than those having symmetric structures, because asymmetric materials may have a lower tendency to recrystallize. Dendrimer substituents may be used to enhance the ability of small molecules to undergo solution processing.

Devices fabricated in accordance with embodiments of the invention may be incorporated into a wide variety of consumer products, including flat panel displays, computer monitors, medical monitors, televisions, billboards, lights for interior or exterior illumination and/or signaling, heads up displays, fully transparent displays, flexible displays, laser printers, telephones, cell phones, personal digital assistants

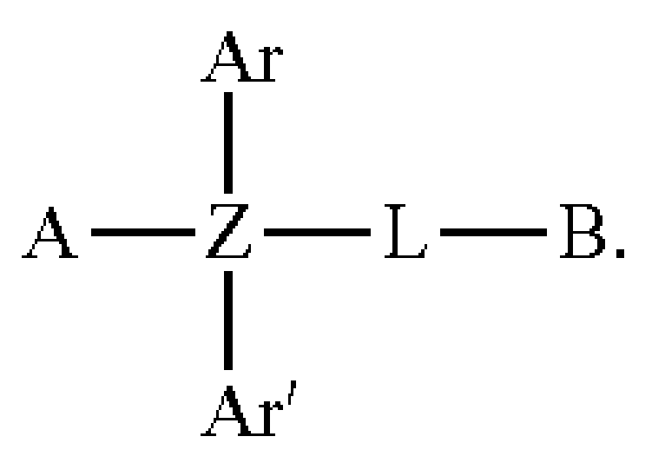
(PDAs), laptop computers, digital cameras, camcorders, viewfinders, micro-displays, vehicles, a large area wall, theater or stadium screen, or a sign. Various control mechanisms may be used to control devices fabricated in accordance with the present invention, including passive matrix and active matrix. Many of the devices are intended for use in a temperature range comfortable to humans, such as 18 degrees C. to 30 degrees C., and more preferably at room temperature (20-25 degrees C.).

The materials and structures described herein may have applications in devices other than OLEDs. For example, other optoelectronic devices such as organic solar cells and organic photodetectors may employ the materials and structures. More generally, organic devices, such as organic transistors, may employ the materials and structures.

The terms halo, halogen, alkyl, cycloalkyl, alkenyl, alkynyl, arylkyl, heterocyclic group, aryl, aromatic group, and heteroaryl are known to the art, and are defined in U.S. Pat. No. 7,279,704 at cols. 31-32, which are incorporated herein by reference.

In one embodiment, a compound having the Formula I is provided:

Formula I



$$A—\overset{\displaystyle Ar}{\underset{\displaystyle Ar'}{Z}}—L—B.$$

In the compound of Formula I, Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, naphthalene, dibenzothiophene and dibenzofuran, which are optionally further substituted. Z is selected from Si and Ge. L is a single bond or comprises an aryl or heteroaryl group having from 5-20 carbon atoms, which is optionally further substituted. A is a group directly bonded to Z and is selected from the group consisting of triphenylene, tetraphenylene, pyrene, naphthalene, fluoranthene, chrysene, phenanthrene, azatriphenylene, azatetraphenylene, azapyrene, azanaphthalene, azafluoranthene, azachrysene, azaphenanthrene, and combinations thereof, which are optionally further substituted with one or more groups selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof.

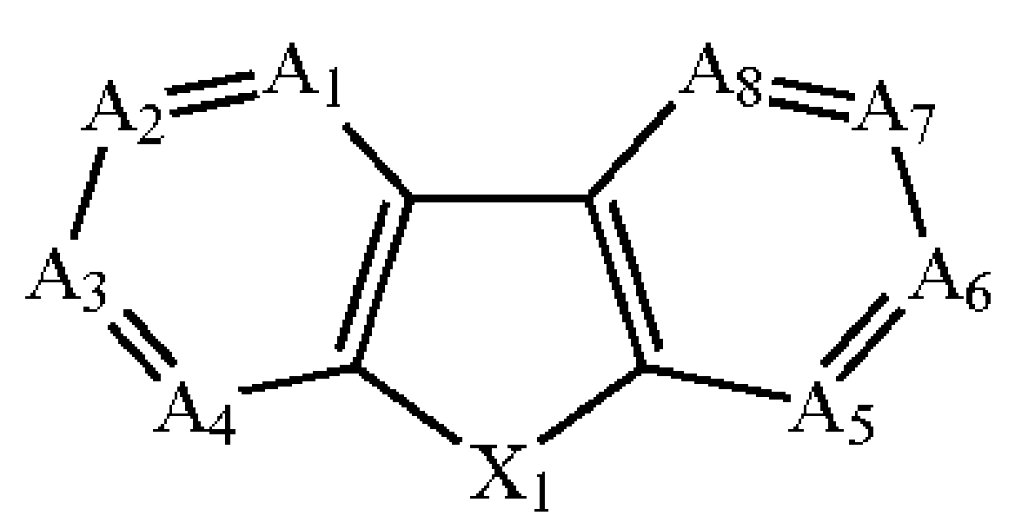
B contains a group selected from the group consisting of carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene, azadibenzoselenophene, and combinations thereof, which are optionally further substituted with one or more groups selected from hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein the substitution is optionally fused to the carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene or azadibenzoselenophene group.

An "aryl" group is an aromatic all carbon group, which can contain one or more fused rings within it. Merely by way of example, and without any limitation, exemplary aryl groups can be phenyl, naphthalene, phenanthrene, corannulene, etc. A "heteroaryl" group is an "aryl" group containing at least one heteroatom. Merely by way of example, and without any limitation, exemplary heteroaryl groups can be pyridine, quinoline, phenanthroline, azacorannulene, etc. Both "aryl" and "heteroaryl" groups can have multiple attachment points connecting them to other fragments.

The "aza" designation in the fragments described above, i.e. aza-dibenzofuran, aza-dibenzonethiophene, etc. means that one or more of the C—H groups in the respective fragment can be replaced by a nitrogen atom, for example, and without any limitation, azatriphenylene encompasses both dibenzo[f,h]quinoxaline and dibenzo[f,h]quinoline. One of ordinary skill in the art can readily envision other nitrogen analogs of the aza-derivatives described above, and all such analogs are intended to be encompassed by the terms as set forth herein.

It is to be understood that when a molecular fragment is described as being a substituent or otherwise attached to another moiety, its name may be written as if it were a fragment (e.g. naphthyl, dibenzofuryl) or as if it were the whole molecule (e.g. naphthalene, dibenzofurna). As used herein, these different ways of designating a substituent or attached fragment are considered to be equivalent.

As used herein, fragments containing the following structure:

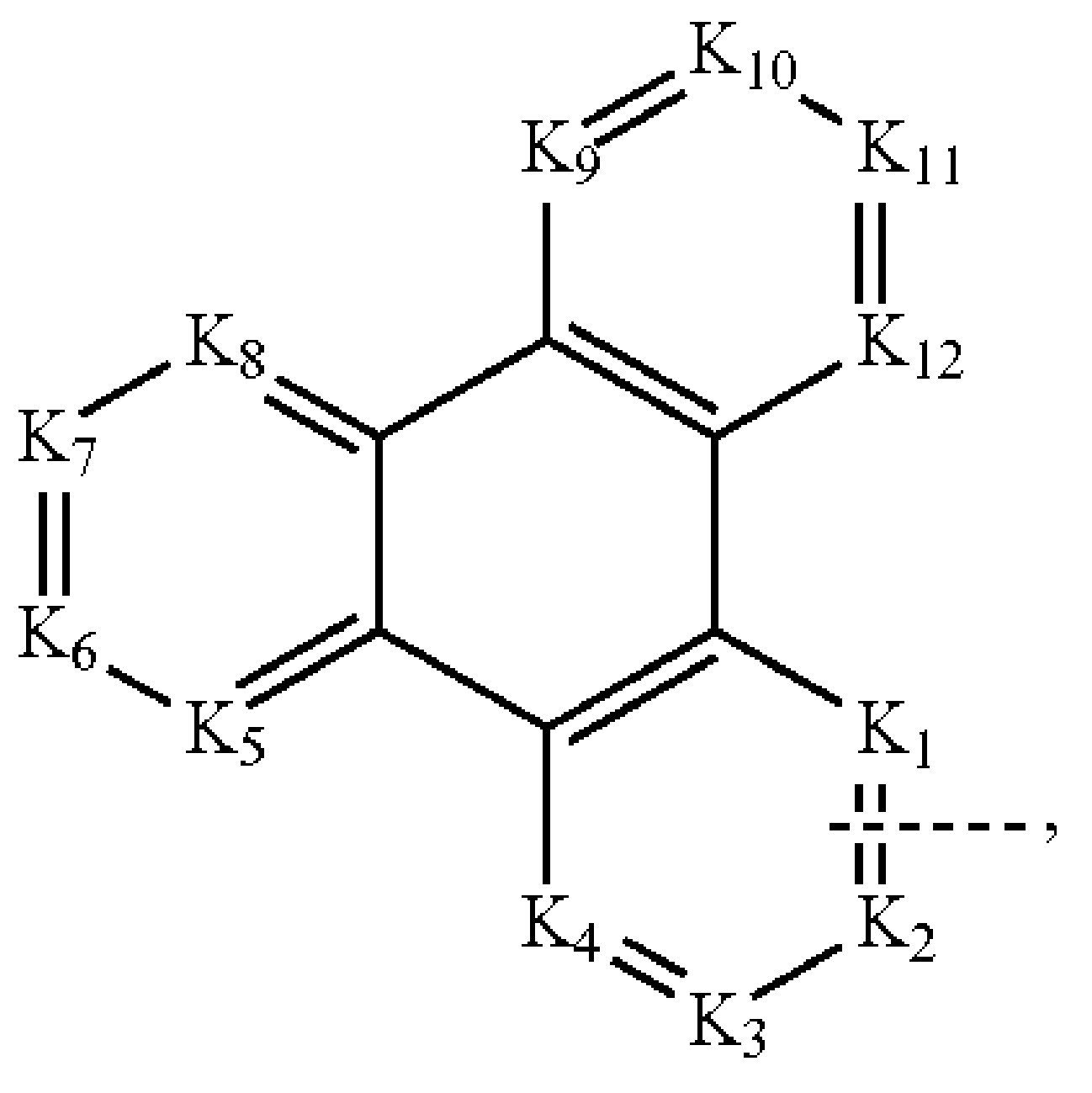


are called DBX groups, i.e. dibenzo X_1, where X_1 is any of the atoms or groups described herein. In the DBX group, A_1-A_8 can comprise carbon or nitrogen.

The novel compounds disclosed herein contain two distinctly different groups, polycyclic aromatic hydrocarbon, such as triphenylene/pyrene-based group A, and DBX- or carbazole-based group B, connected with a silane or germane spacer, resulting in an asymmetric structure. These compounds have a number of advantageous properties when used in OLED devices. Firstly, triphenylene and pyrene have excellent charge-transport capabilities, while DBX and carbazole have appropriate LUMO and HOMO levels, for electron and hole injection from adjacent layers. The combination of triphenylene/pyrene and DBX or carbazole results in compounds favorable for both charge injection and transport. Further derivatization on these groups can maintain, and even improve, the excellent charge injection and transport characteristics. Secondly, the silane and germane spacers break the conjugation between groups A and B, retaining the high triplet energies of the individual groups in the entire molecule, and thus effectively reducing quenching and allowing for the use of compounds of Formula I with high triplet energy emitters.

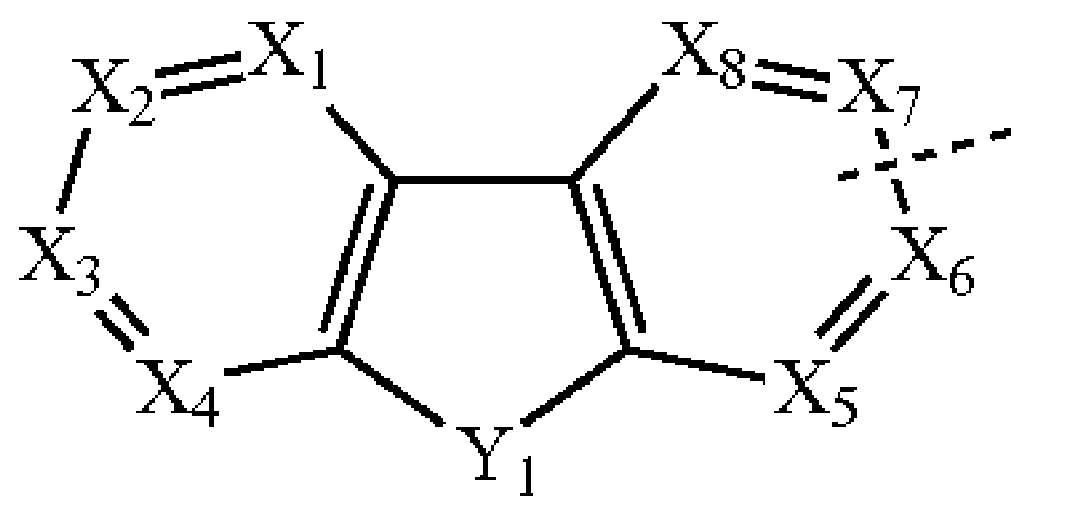
The compounds of Formula I have additional advantages over known symmetric analogs because compounds of Formula I are less prone to crystallization. As a result, compounds of Formula I possess improved film uniformity, which, without being bound by theory, is believed to be a result of reduction in phase separation between the emitters and host materials in OLEDs. The novel compounds of Formula I can be used to improve OLED device performance parameters, such as emission spectrum line shape, efficiency and lifetime. Furthermore, compounds of Formula I also tend to be soluble in organic solvents such as toluene, xylene, and 3-phenoxytoluene, and are amenable to solution processing which is highly desirable for low-cost lighting applications.

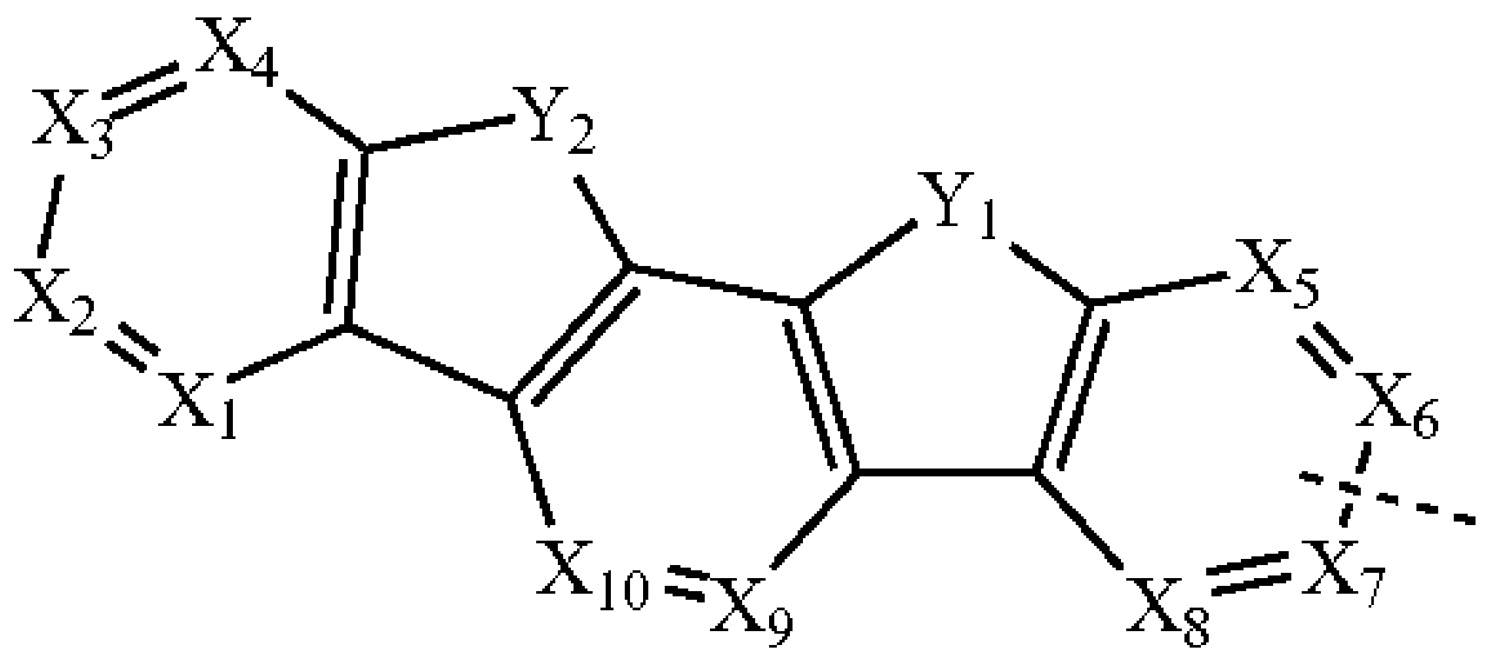
In one embodiment, A is

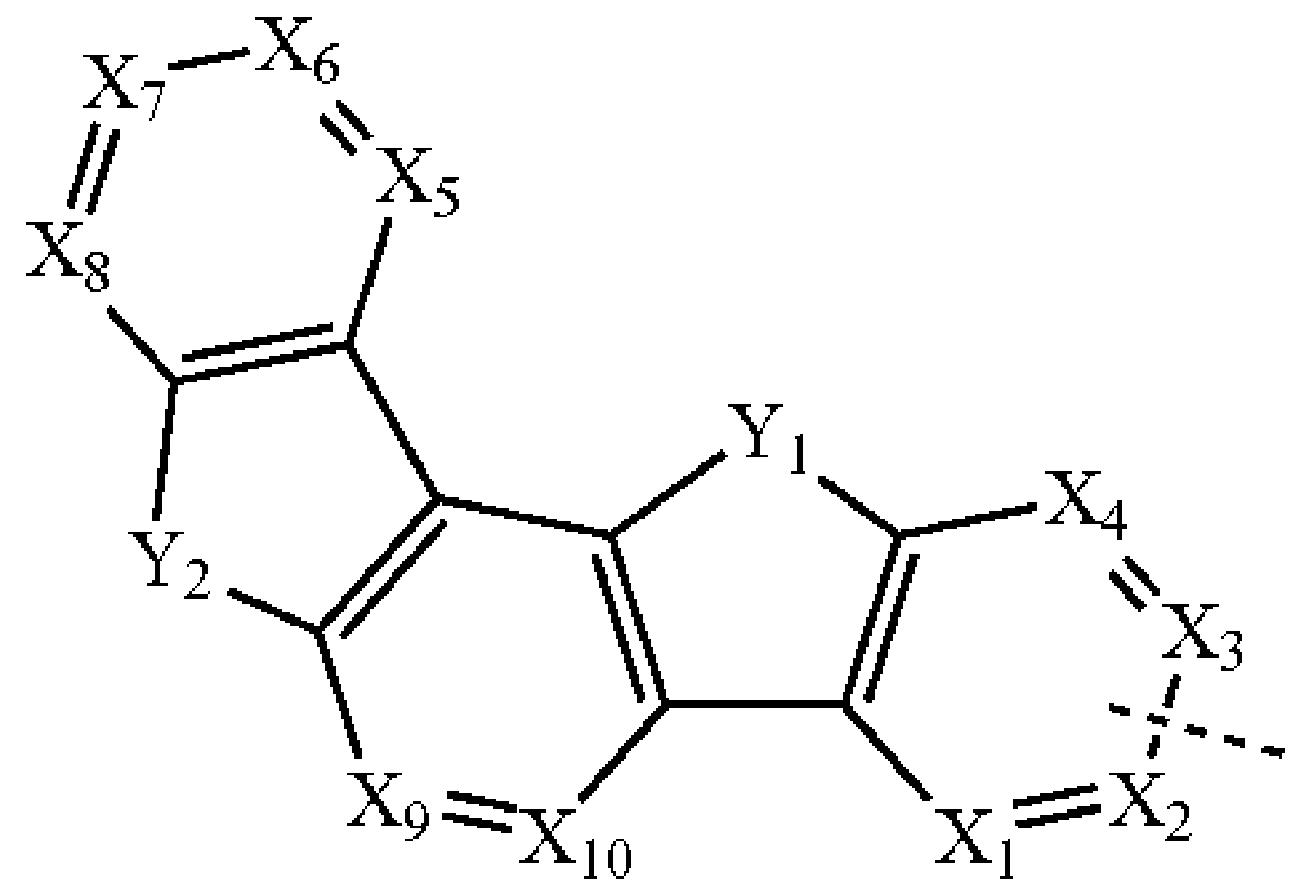


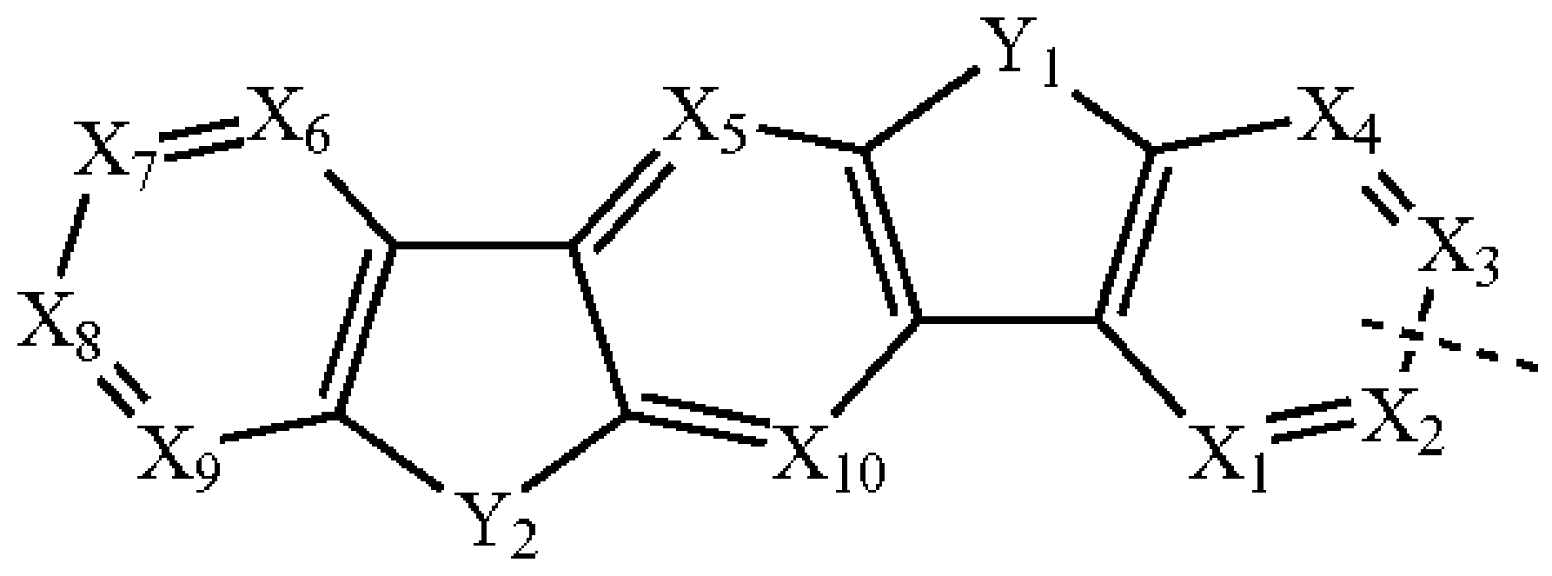
wherein K_1 to K_{12} are independently selected from N and C—R', and wherein R' is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof.

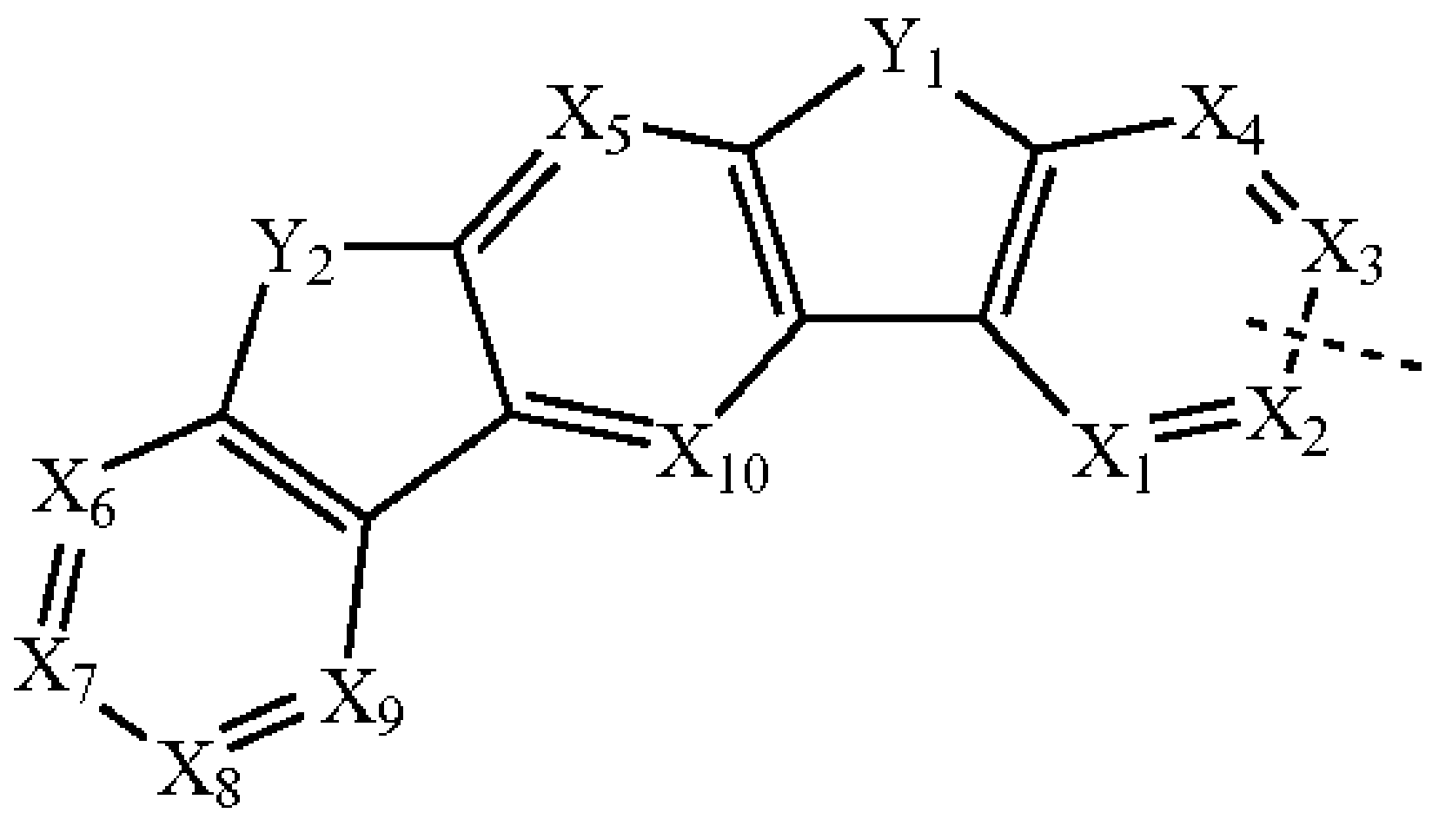
In one embodiment, B is selected from the group consisting of:

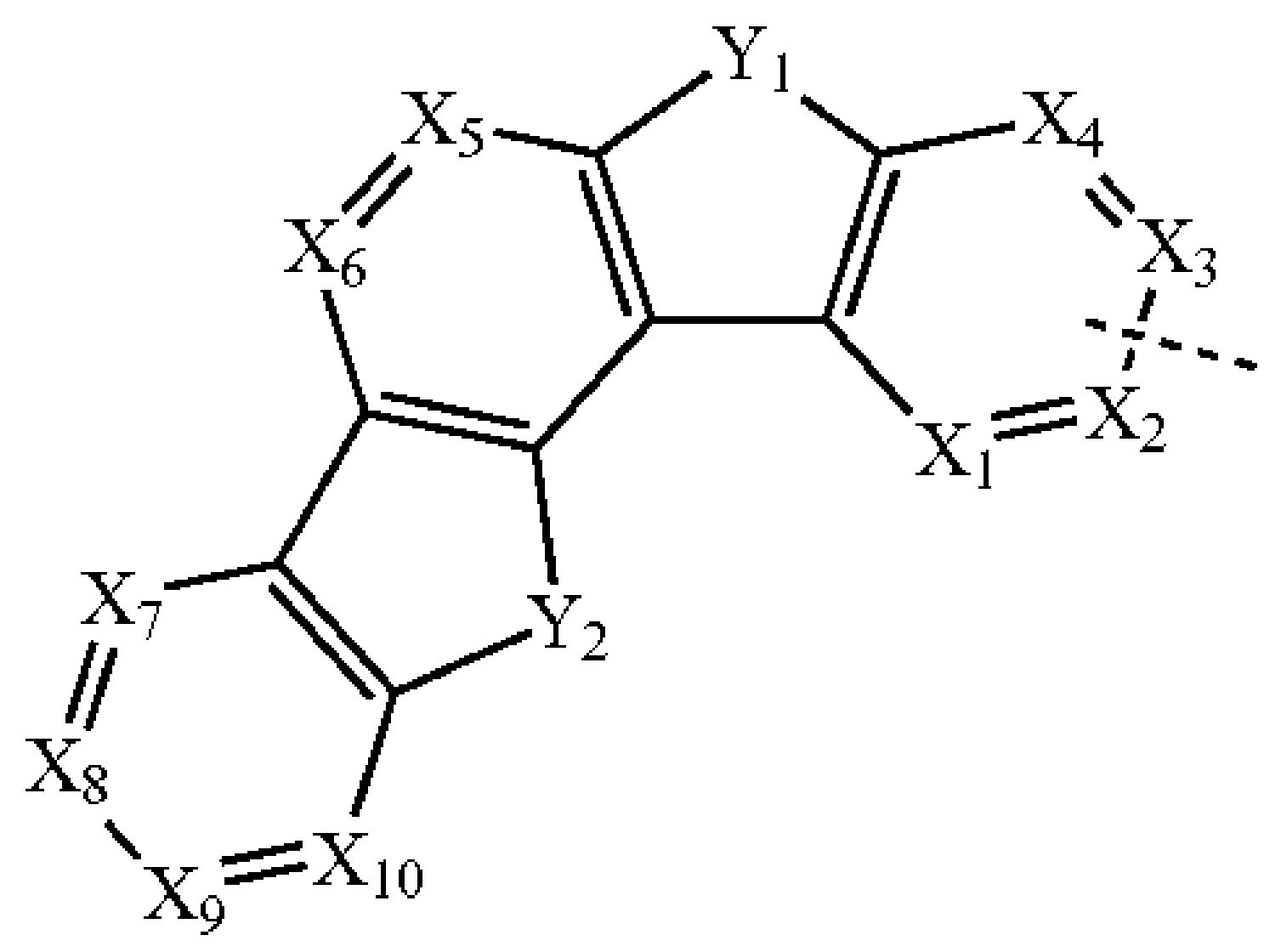












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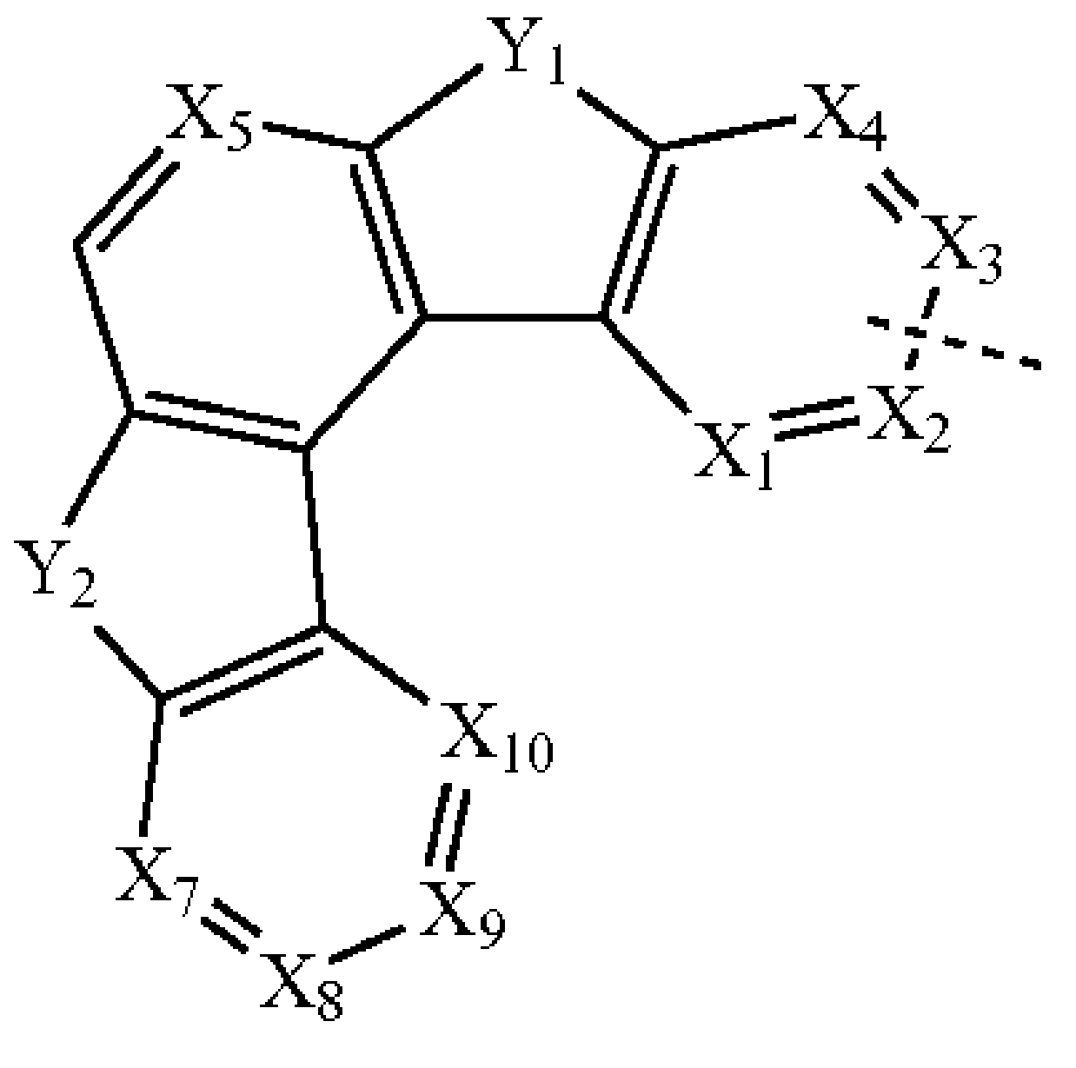
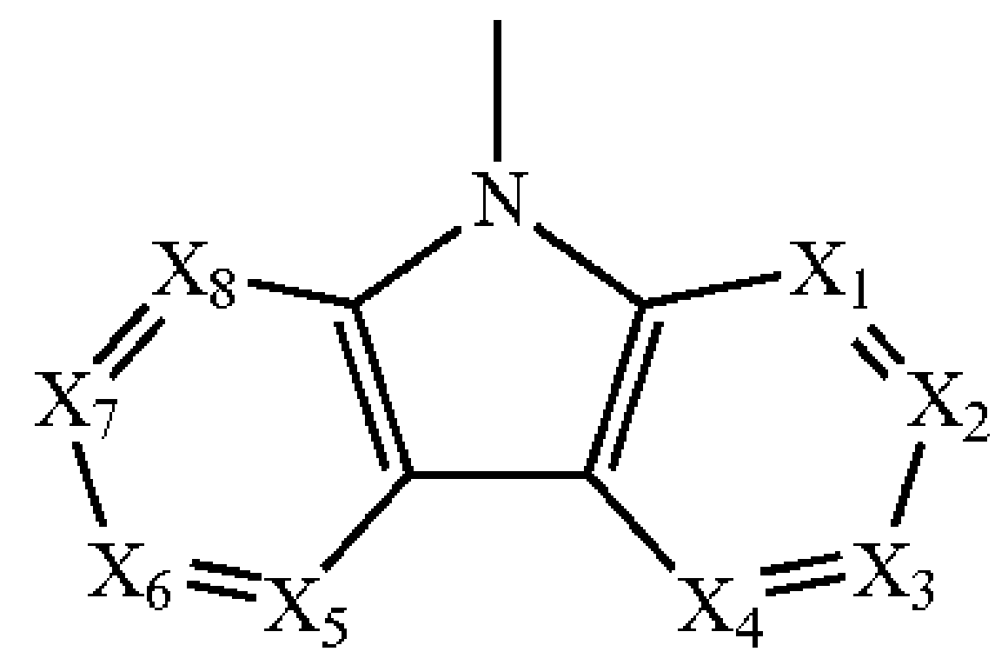
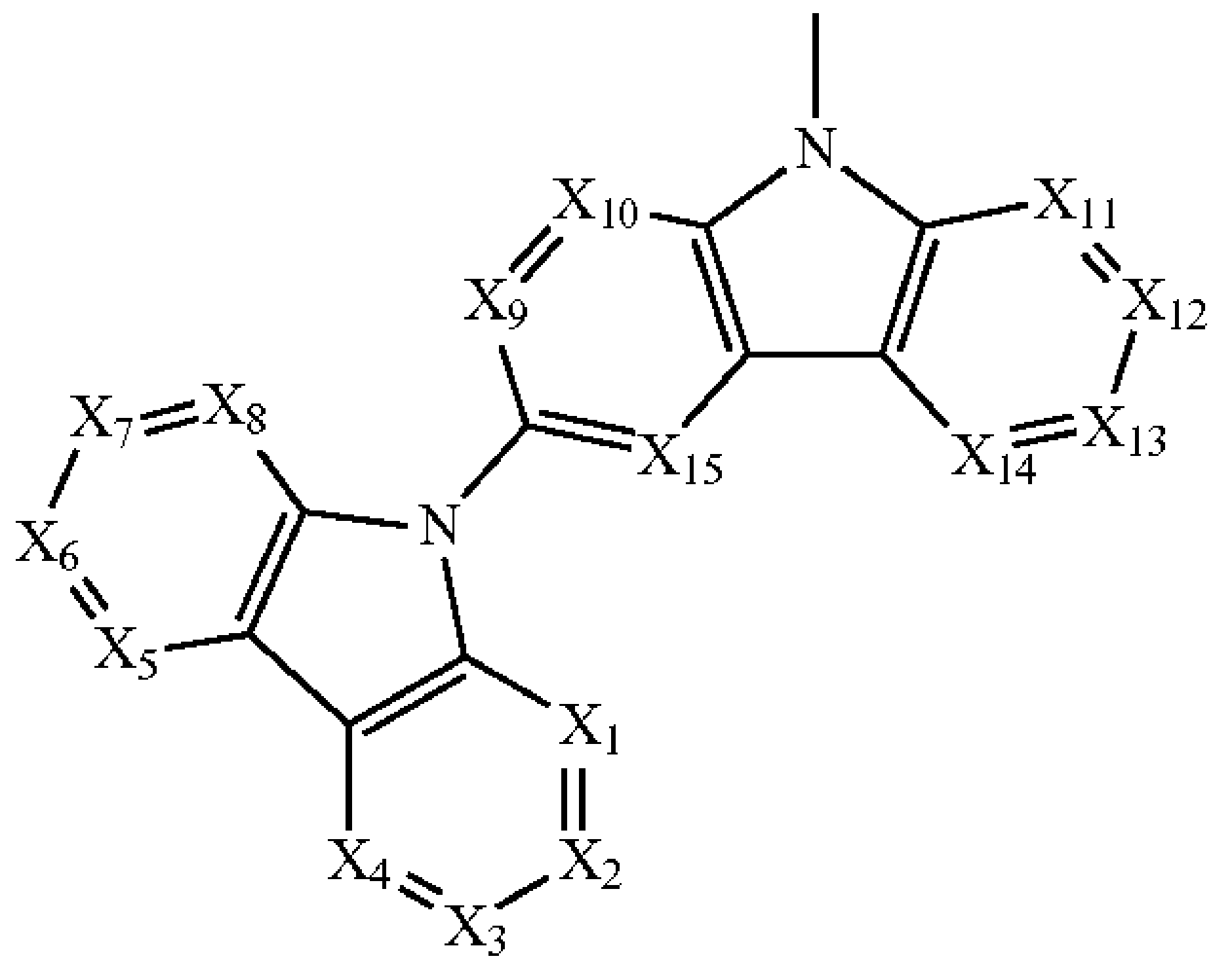
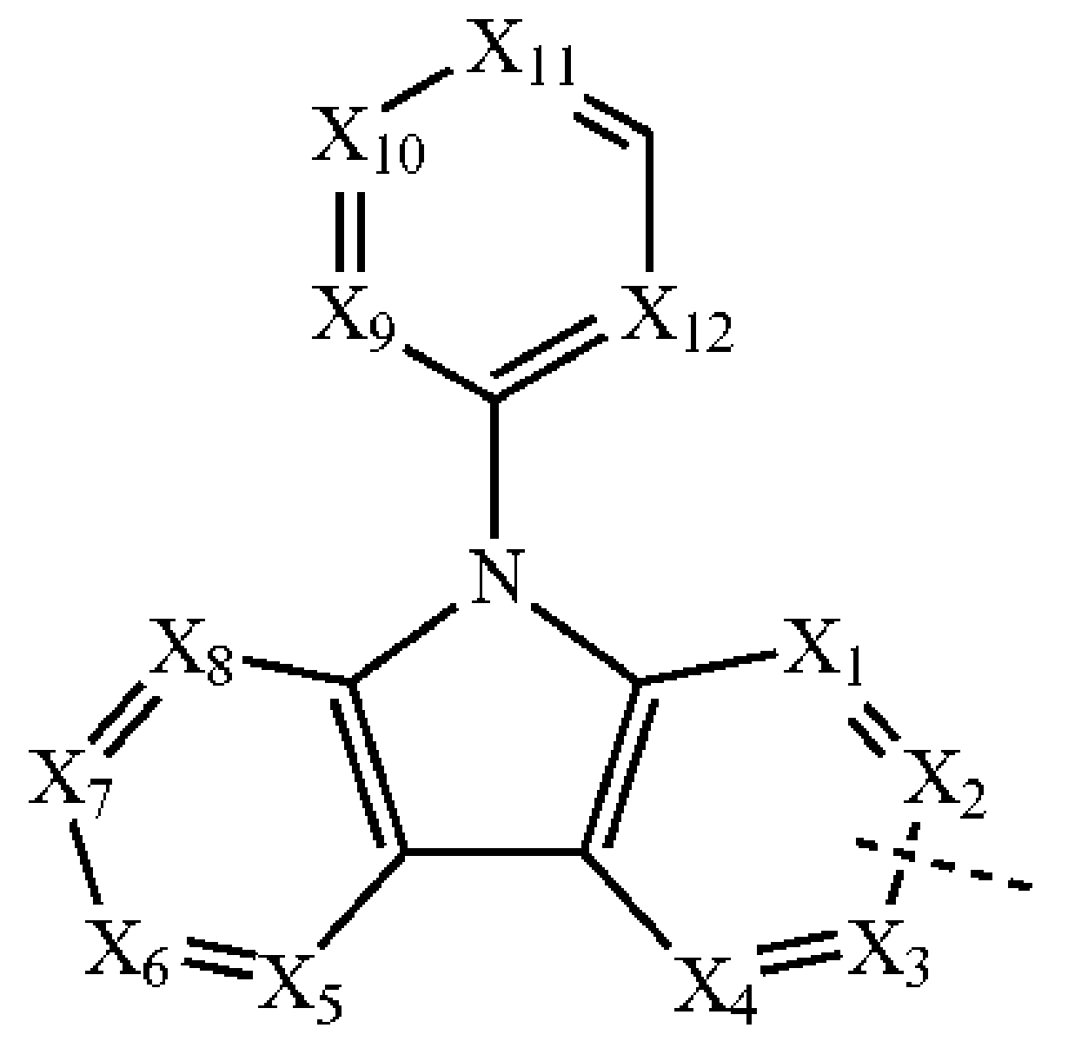


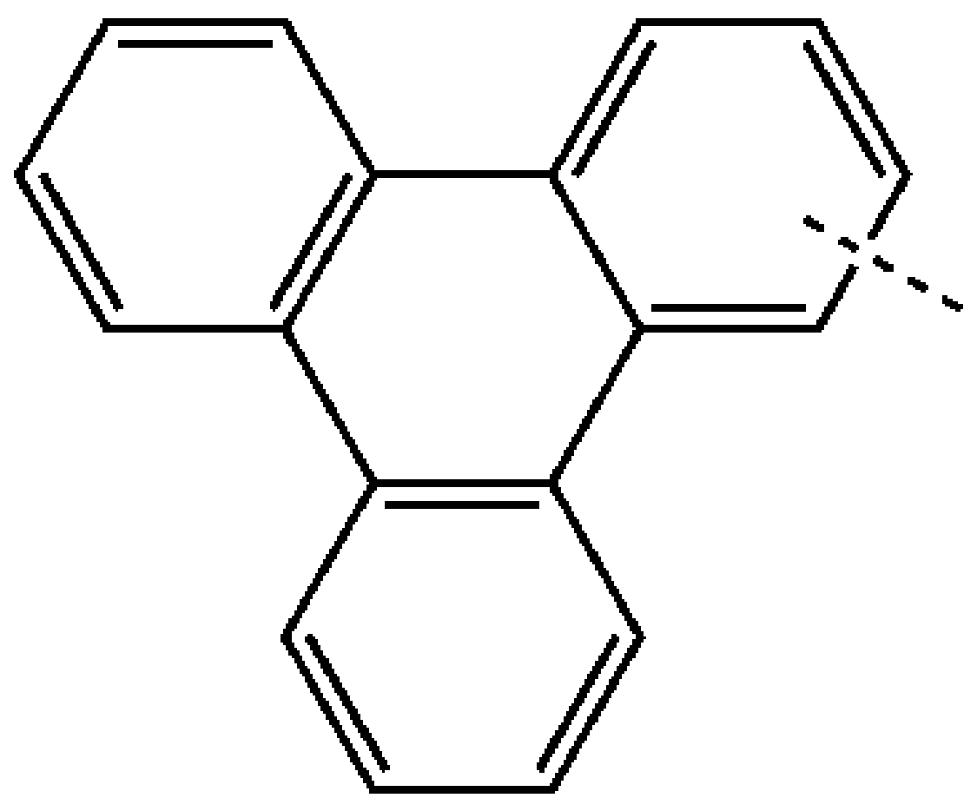


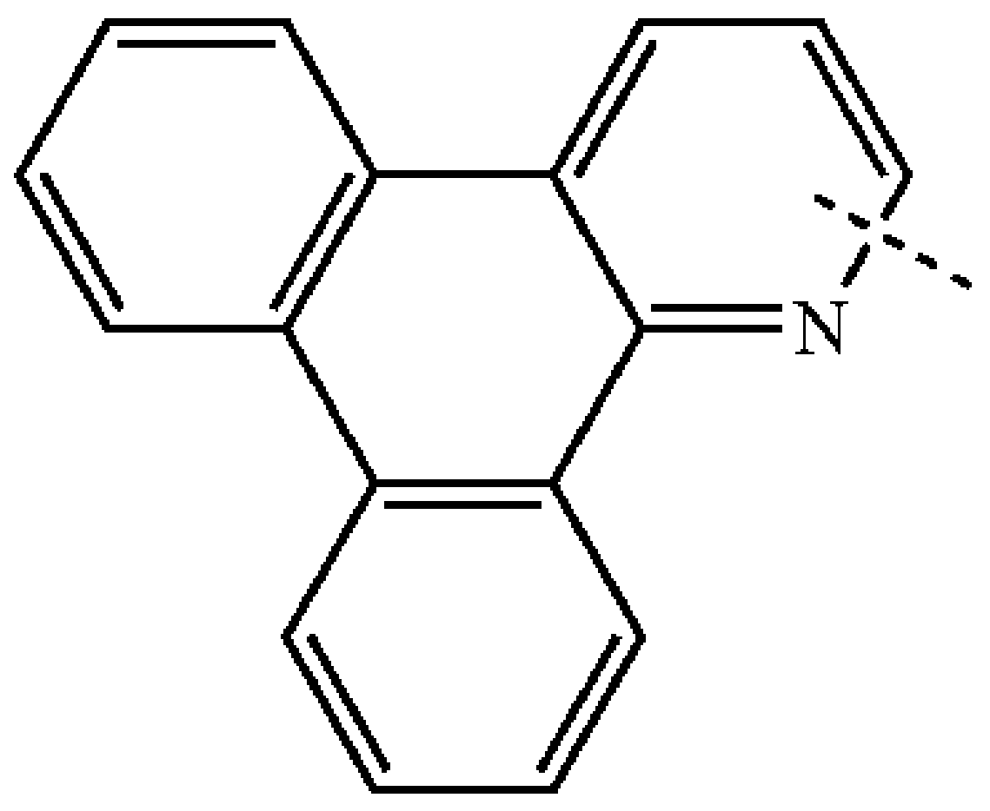


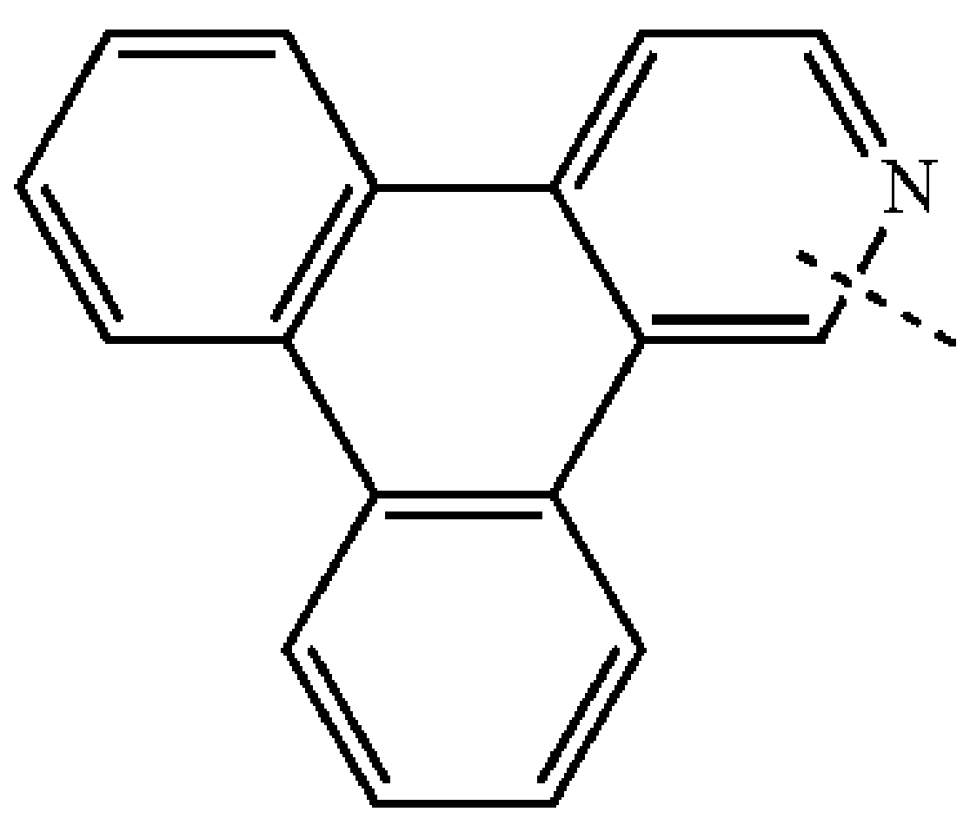


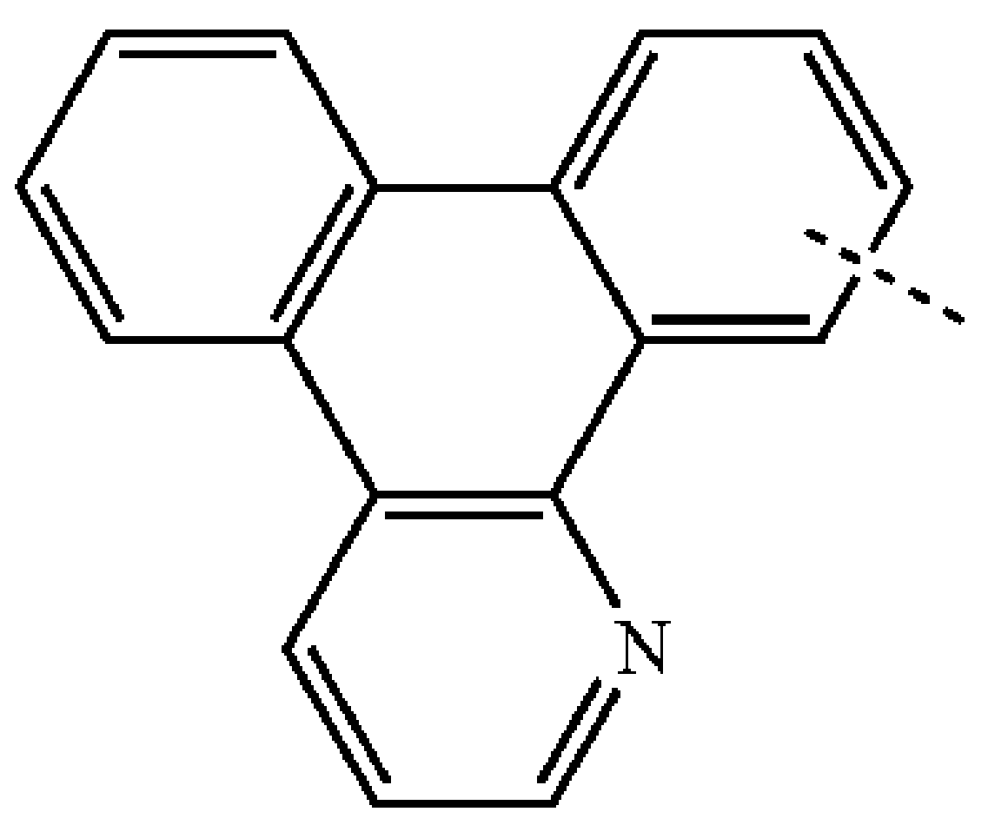
wherein X_1-X_{15} are independently selected from the group consisting of N and C—R", wherein R" is selected from a group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein Y_1 and Y_2 are independently selected from the group consisting of O, S, and Se. The dashed lines in the chemical structures disclosed herein represent a bond through any position on that group capable of forming a single bond with another atom.

In one embodiment, A is selected from the group consisting of:









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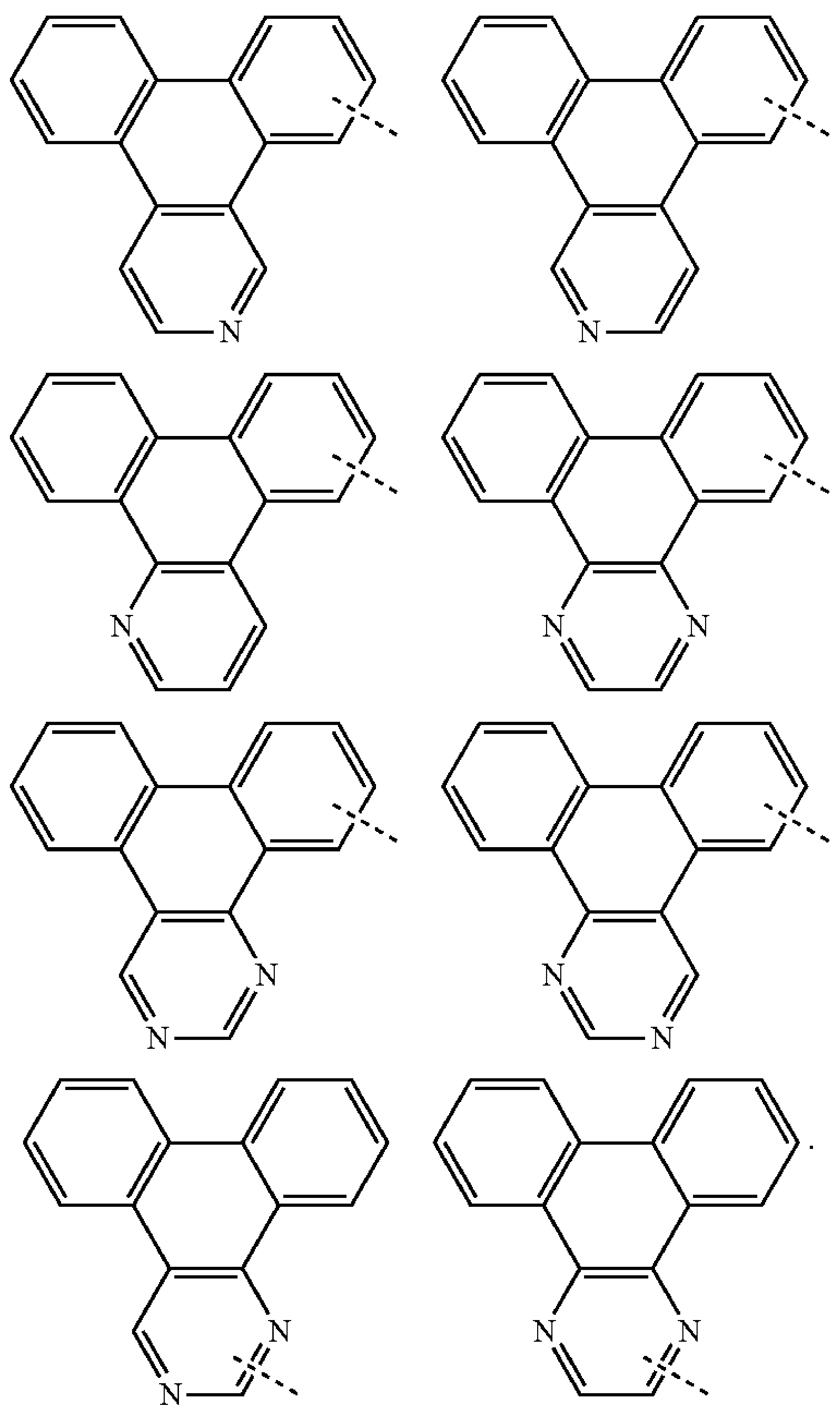

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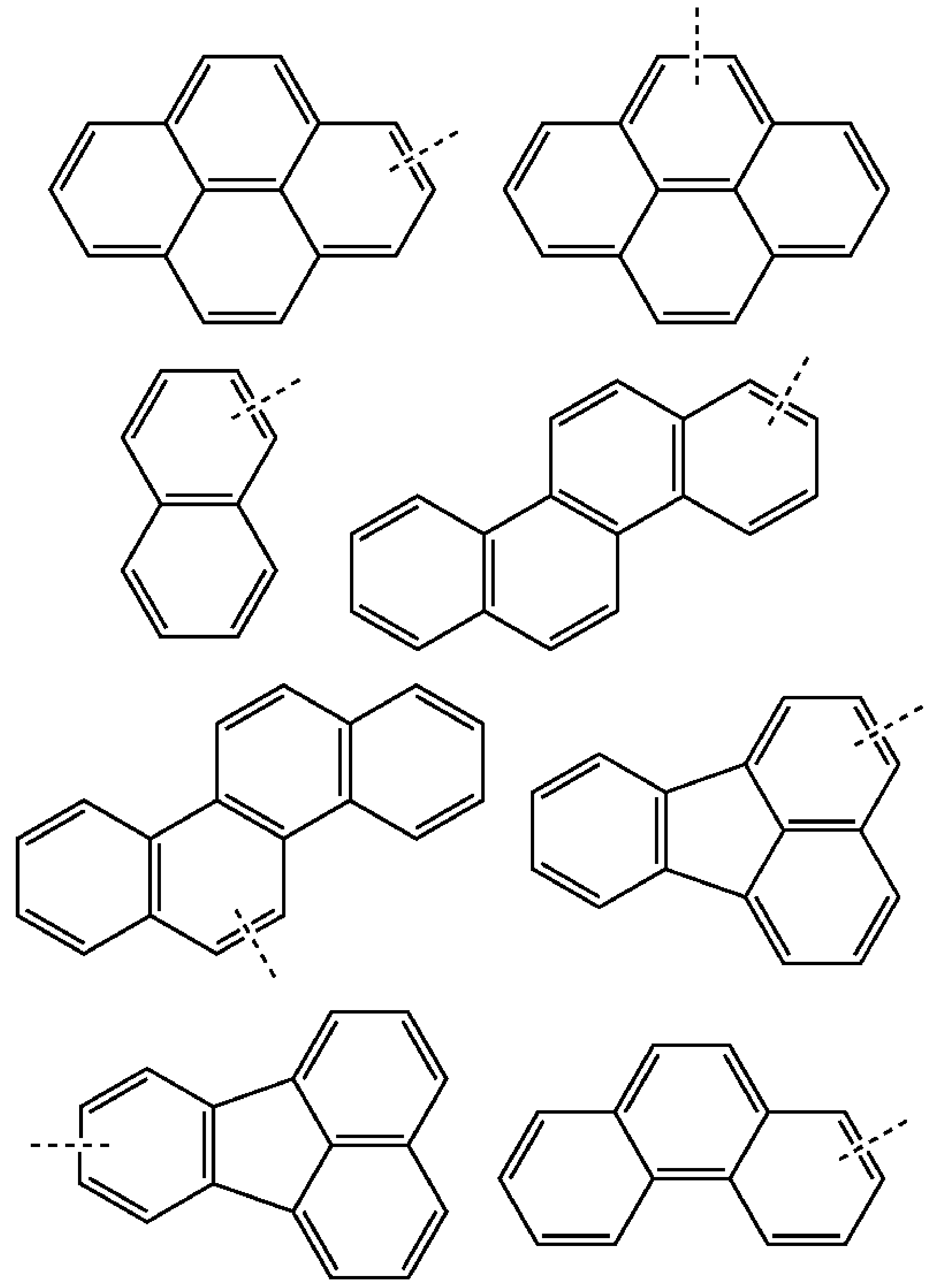

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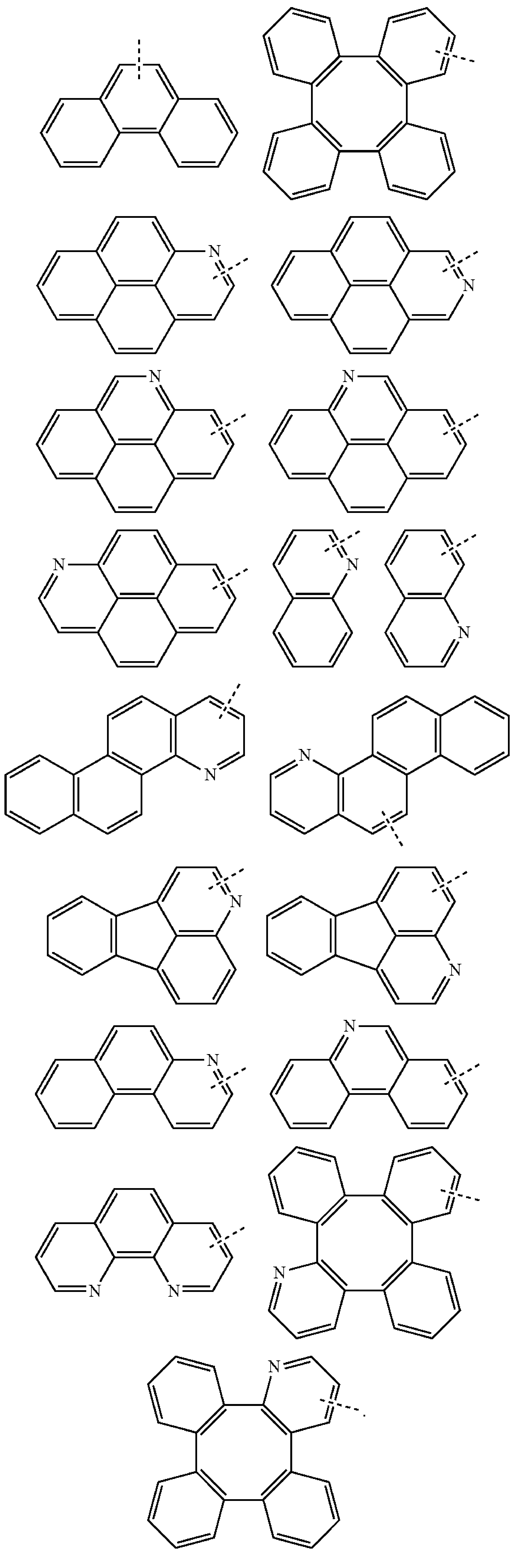
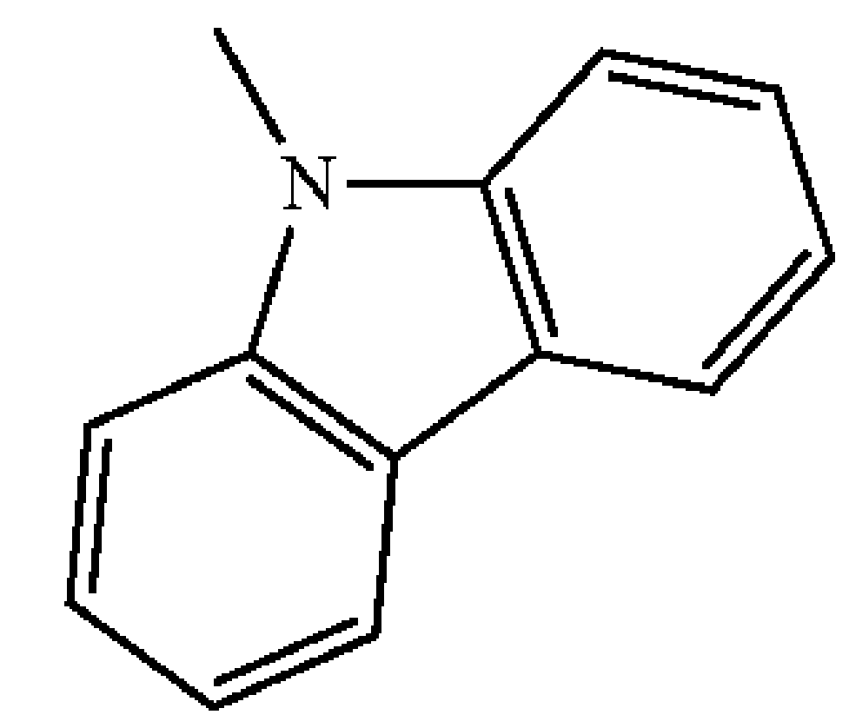
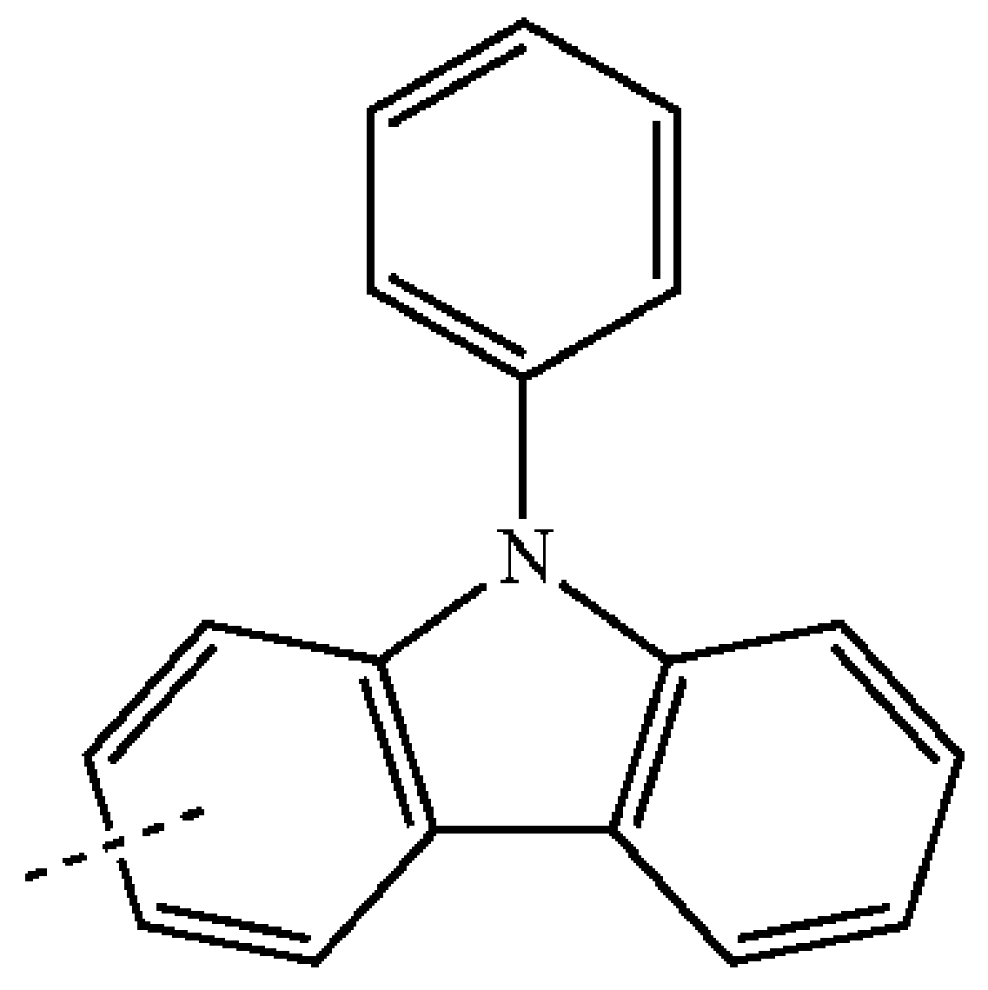
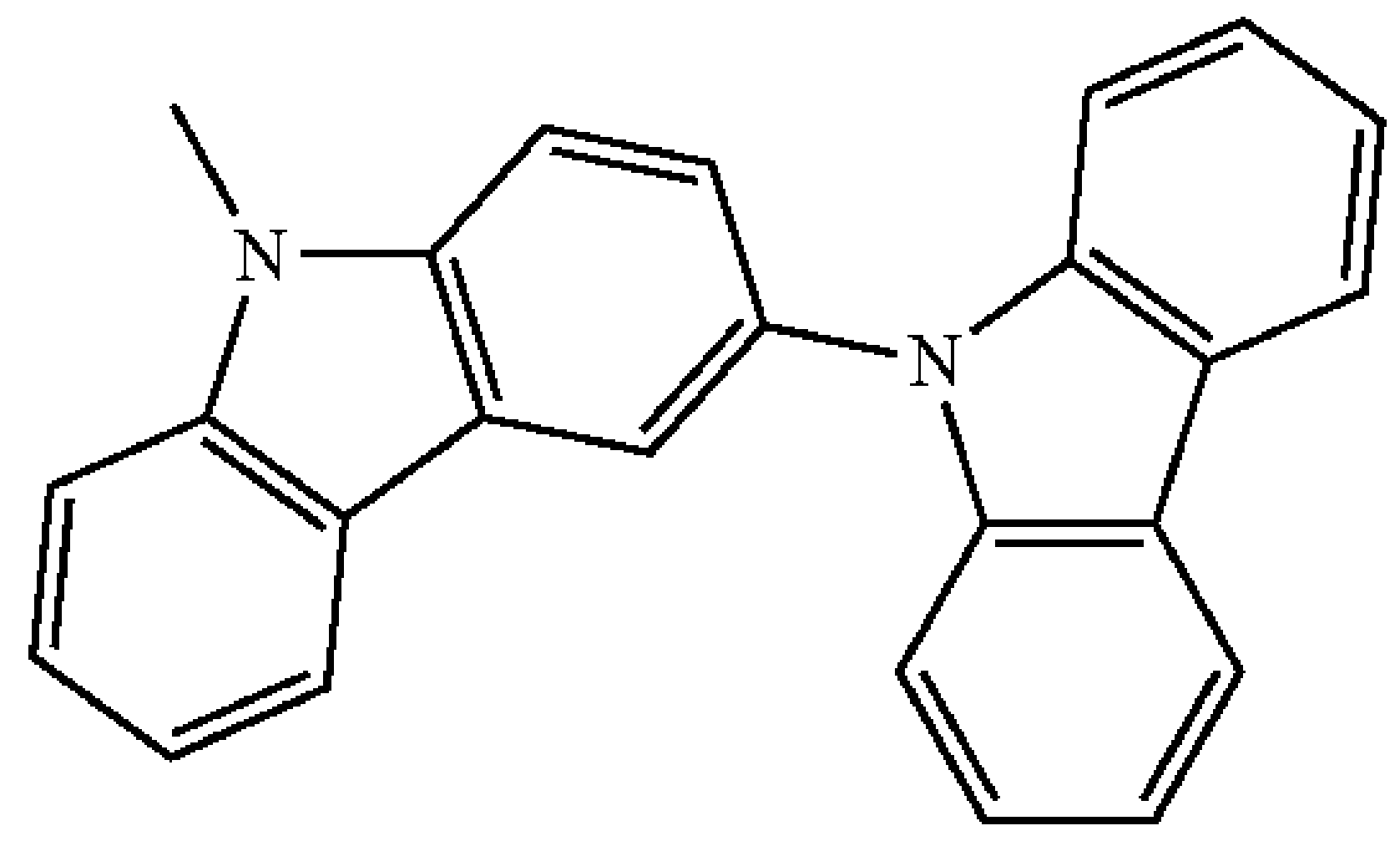
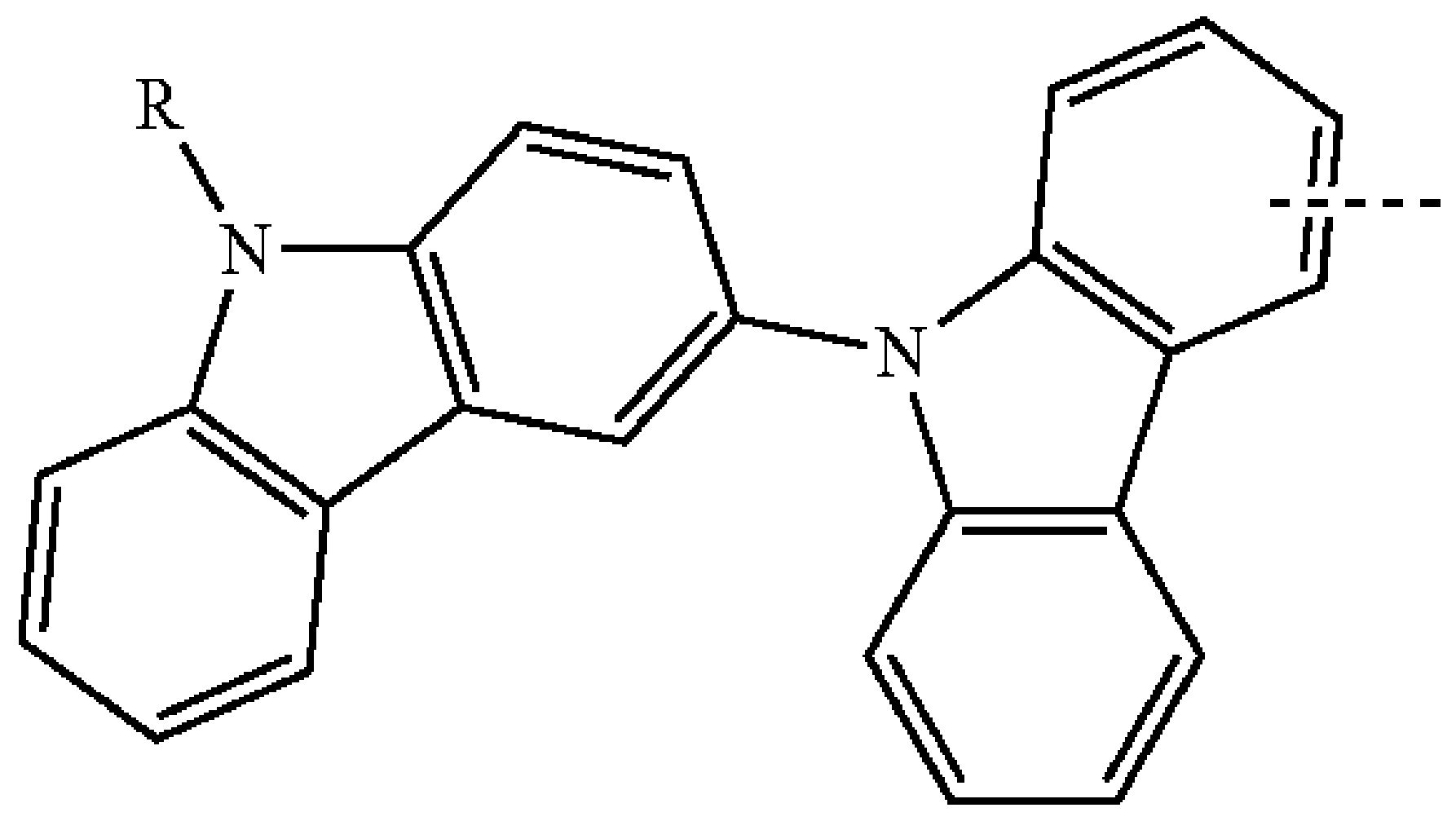


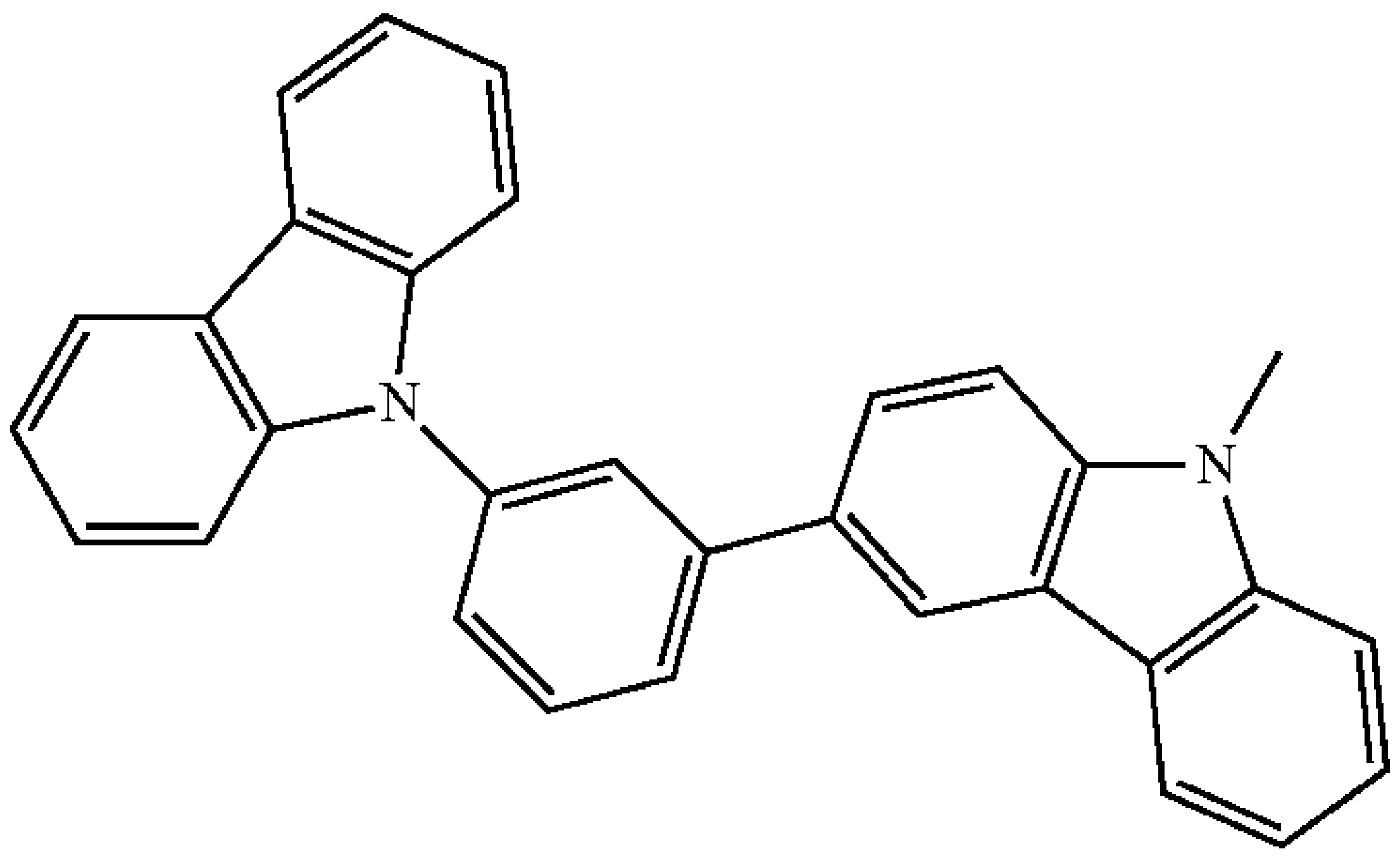
In one embodiment, B is selected from the group consisting of:

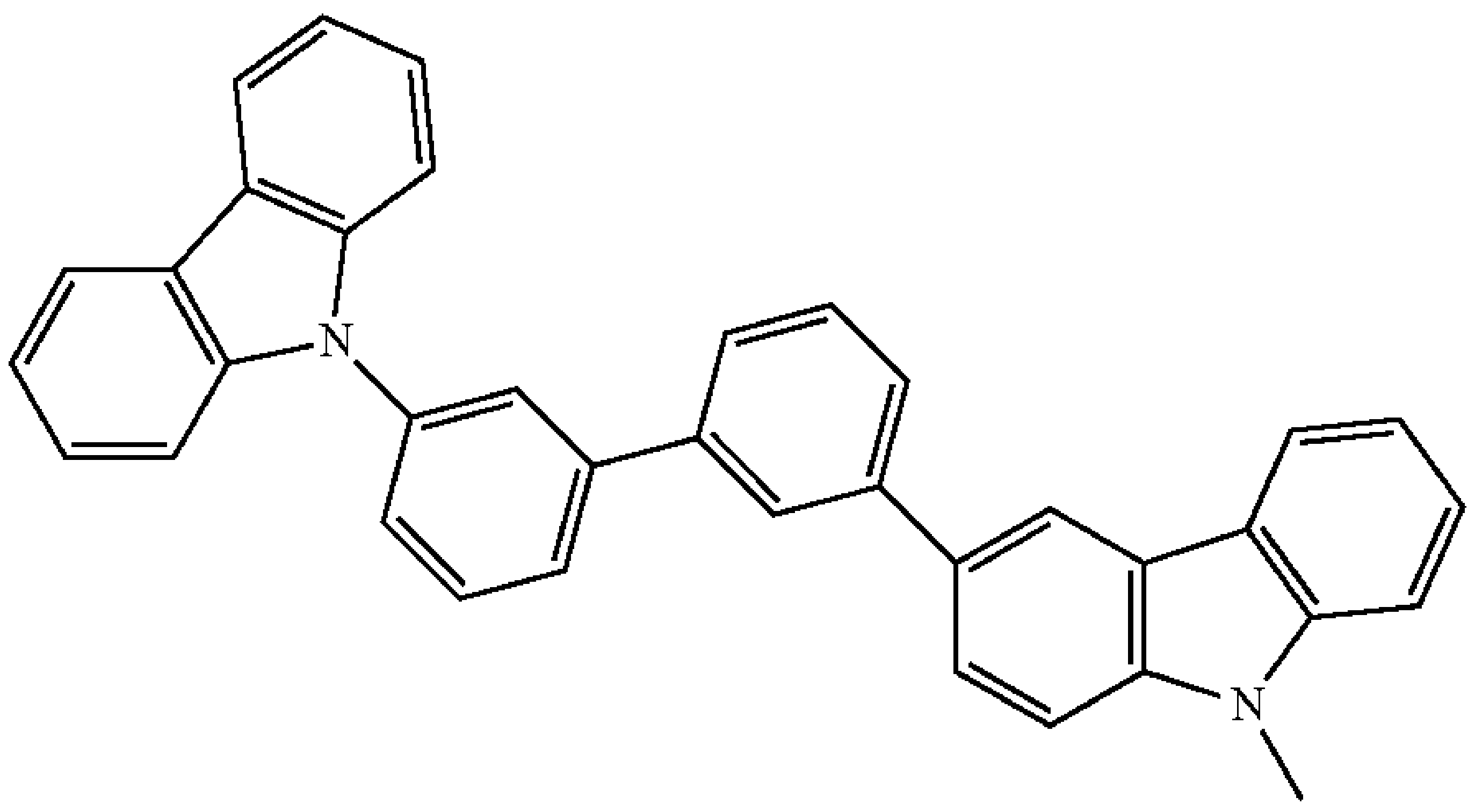


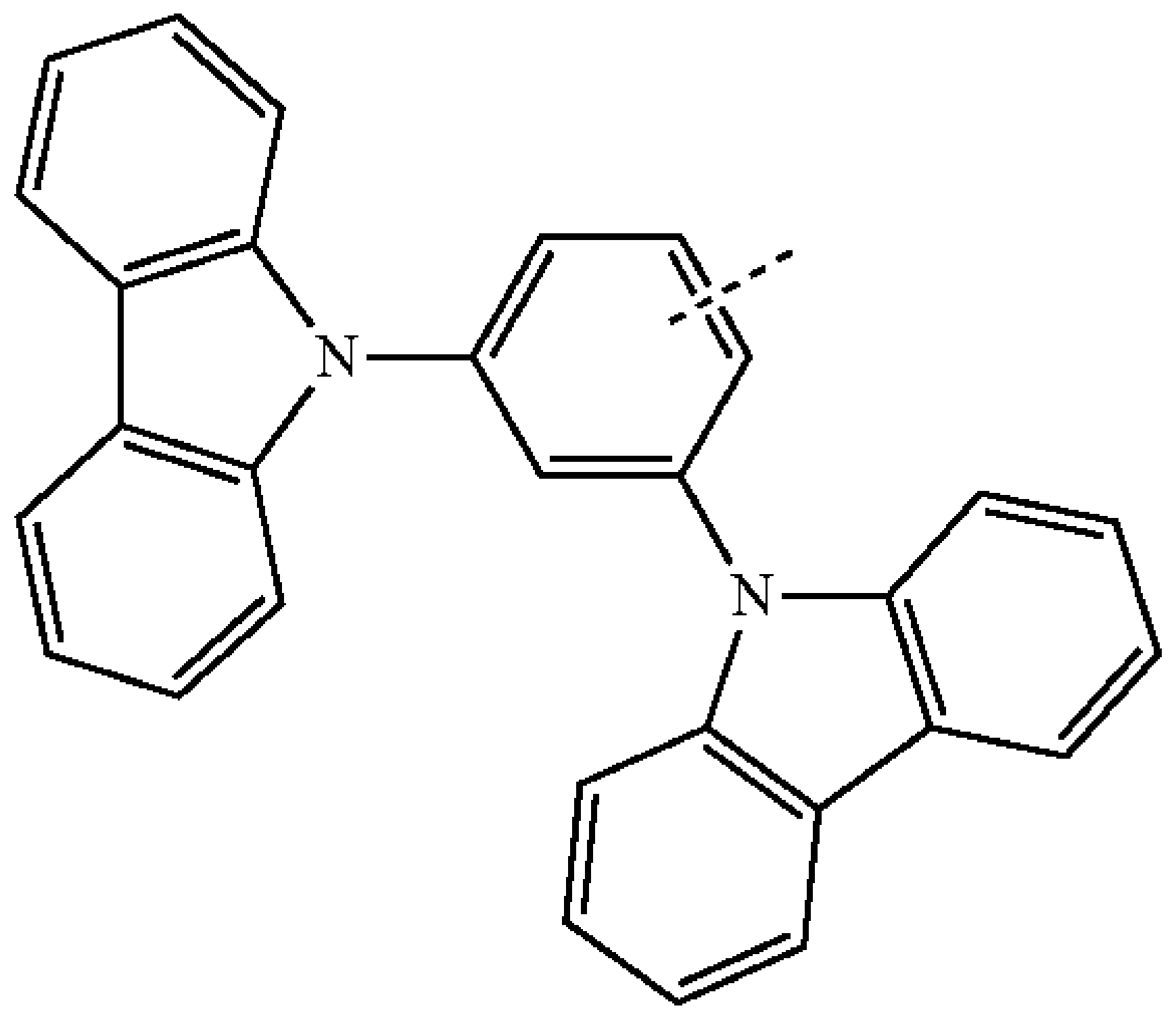












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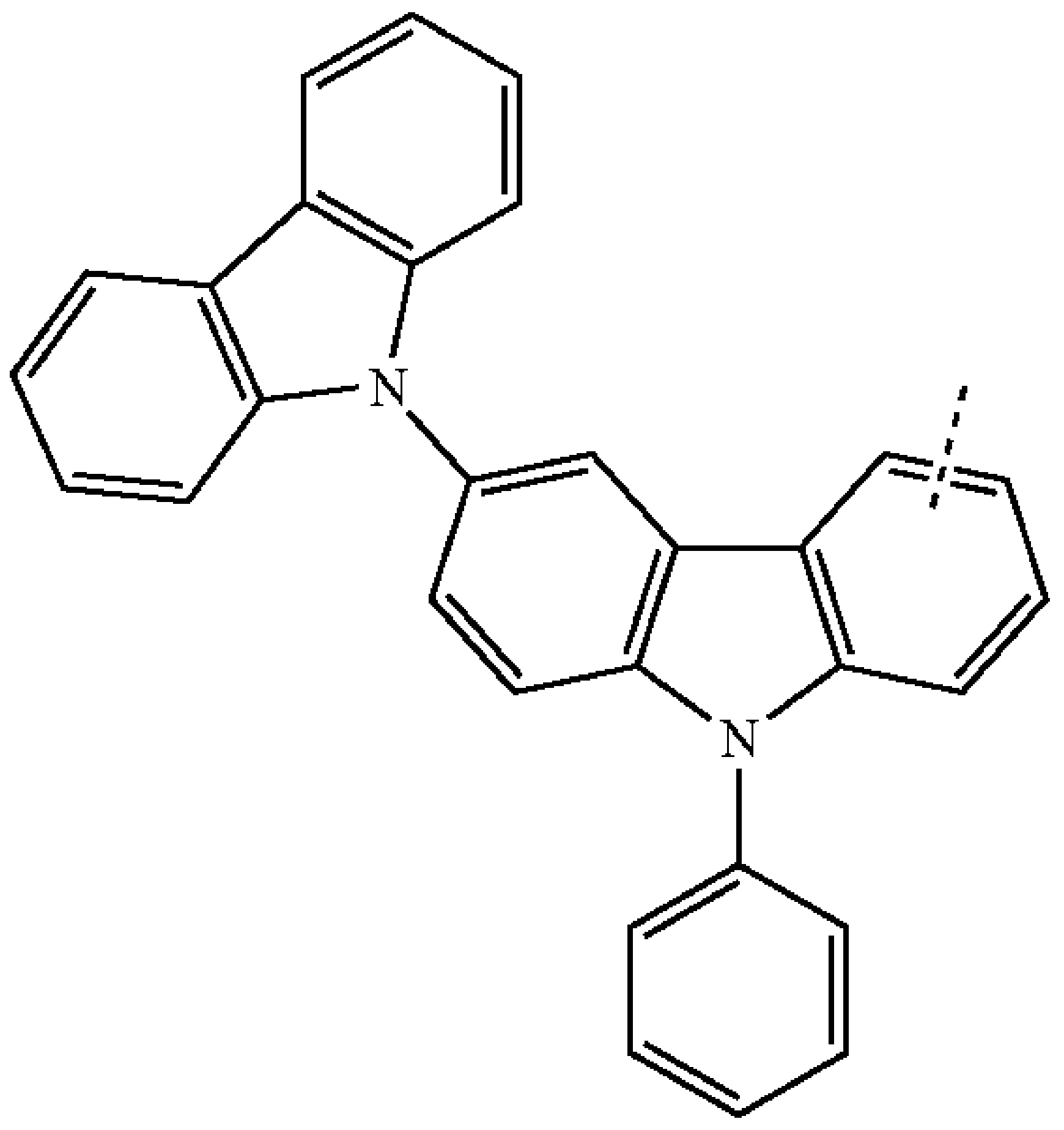

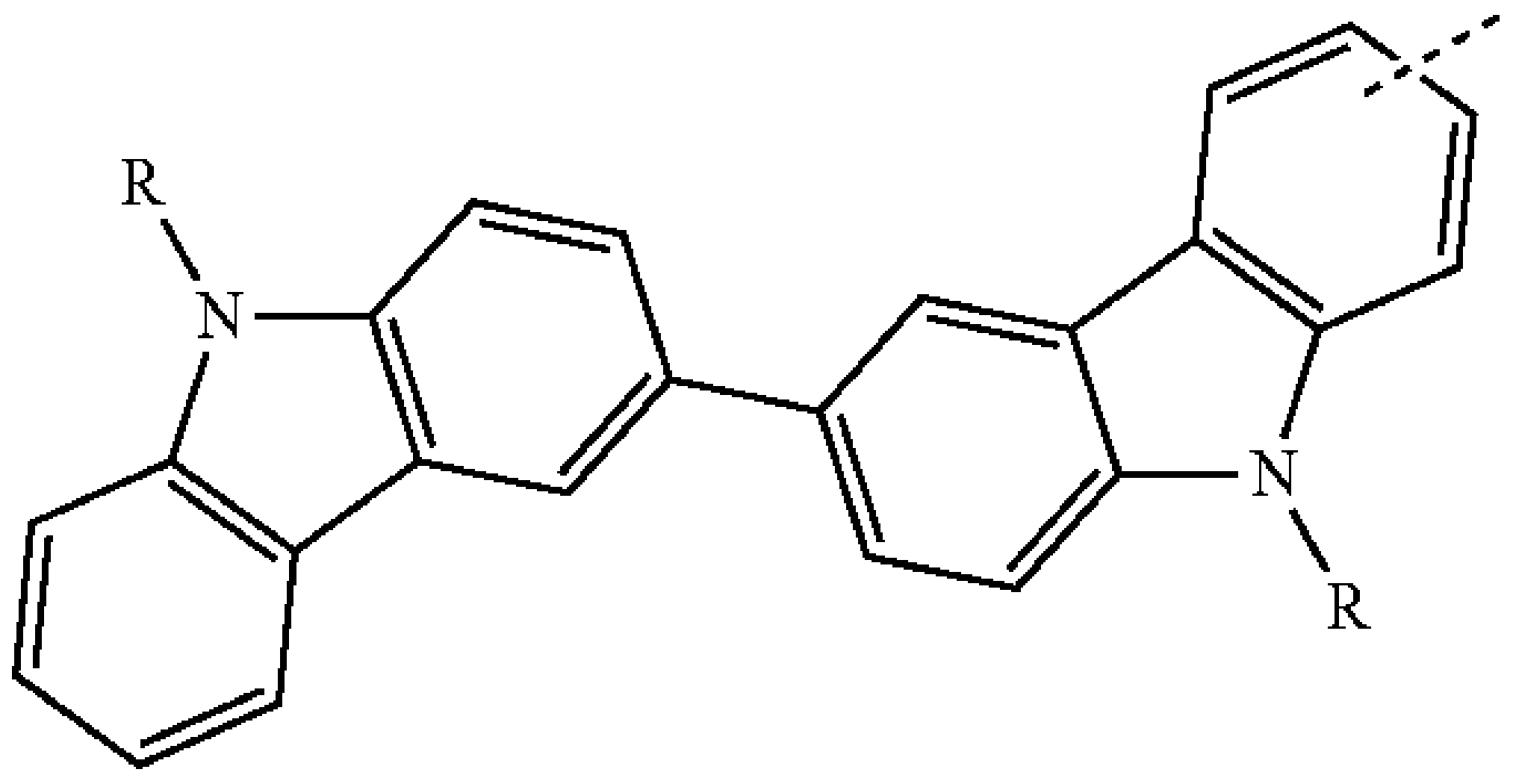

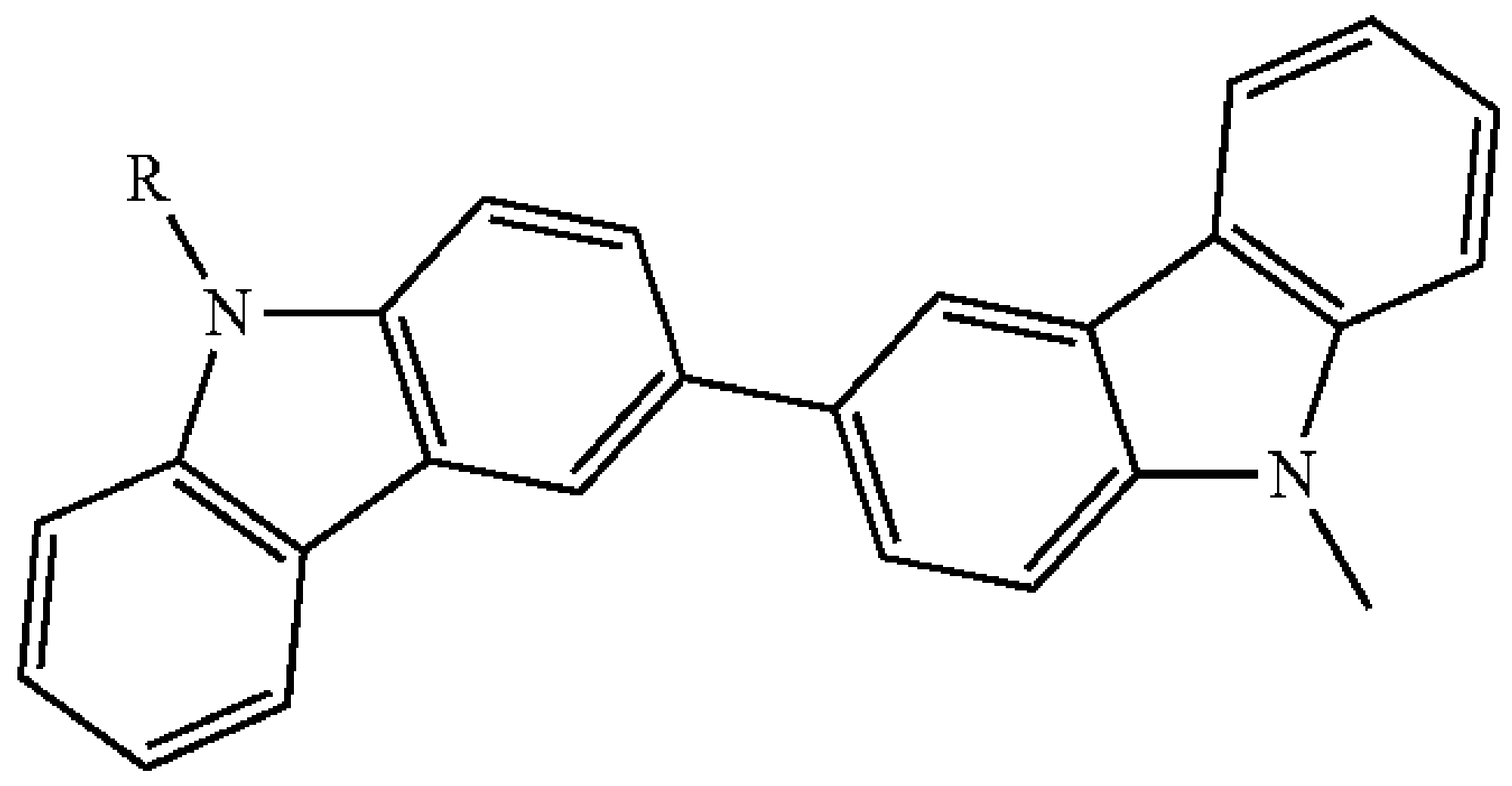

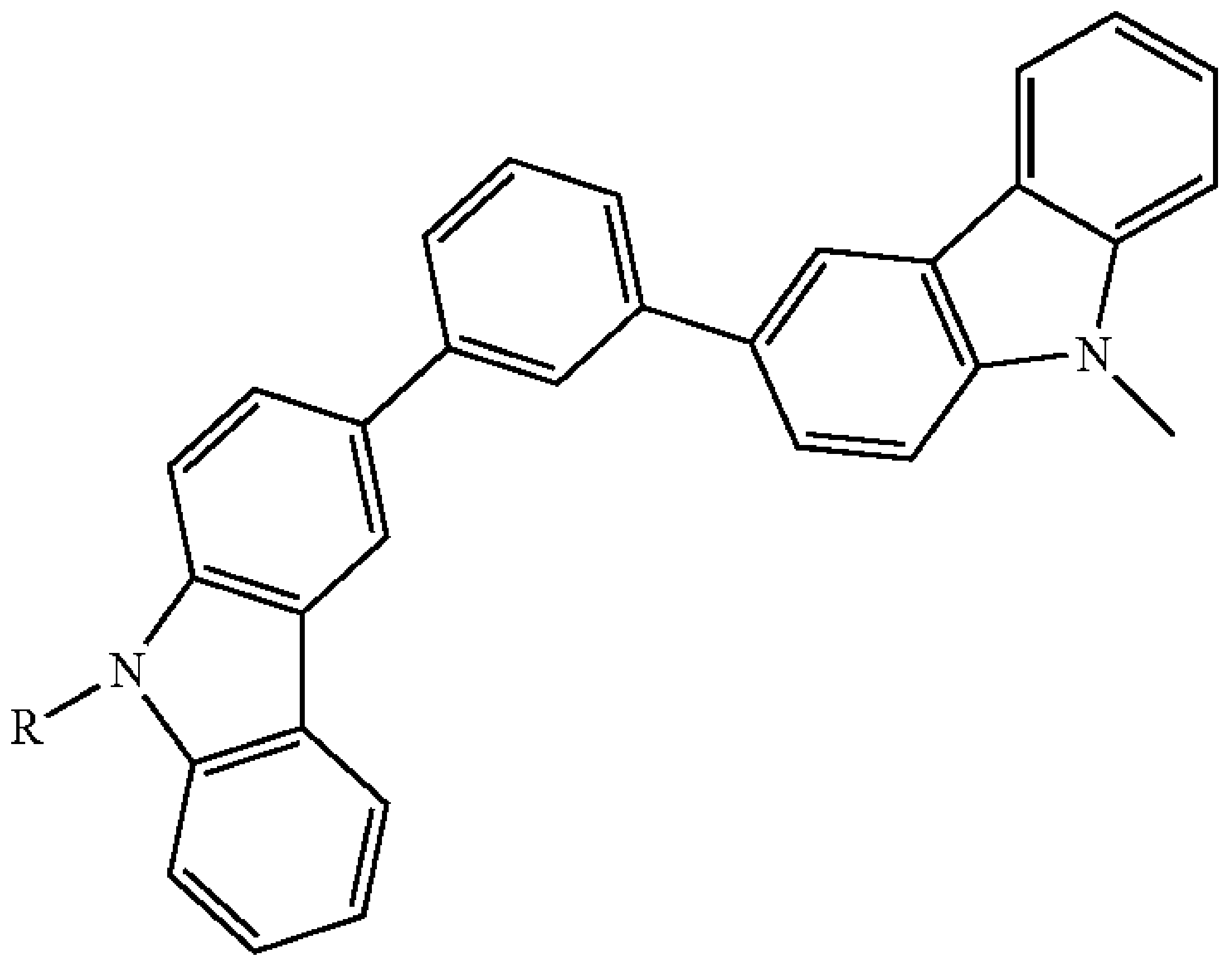

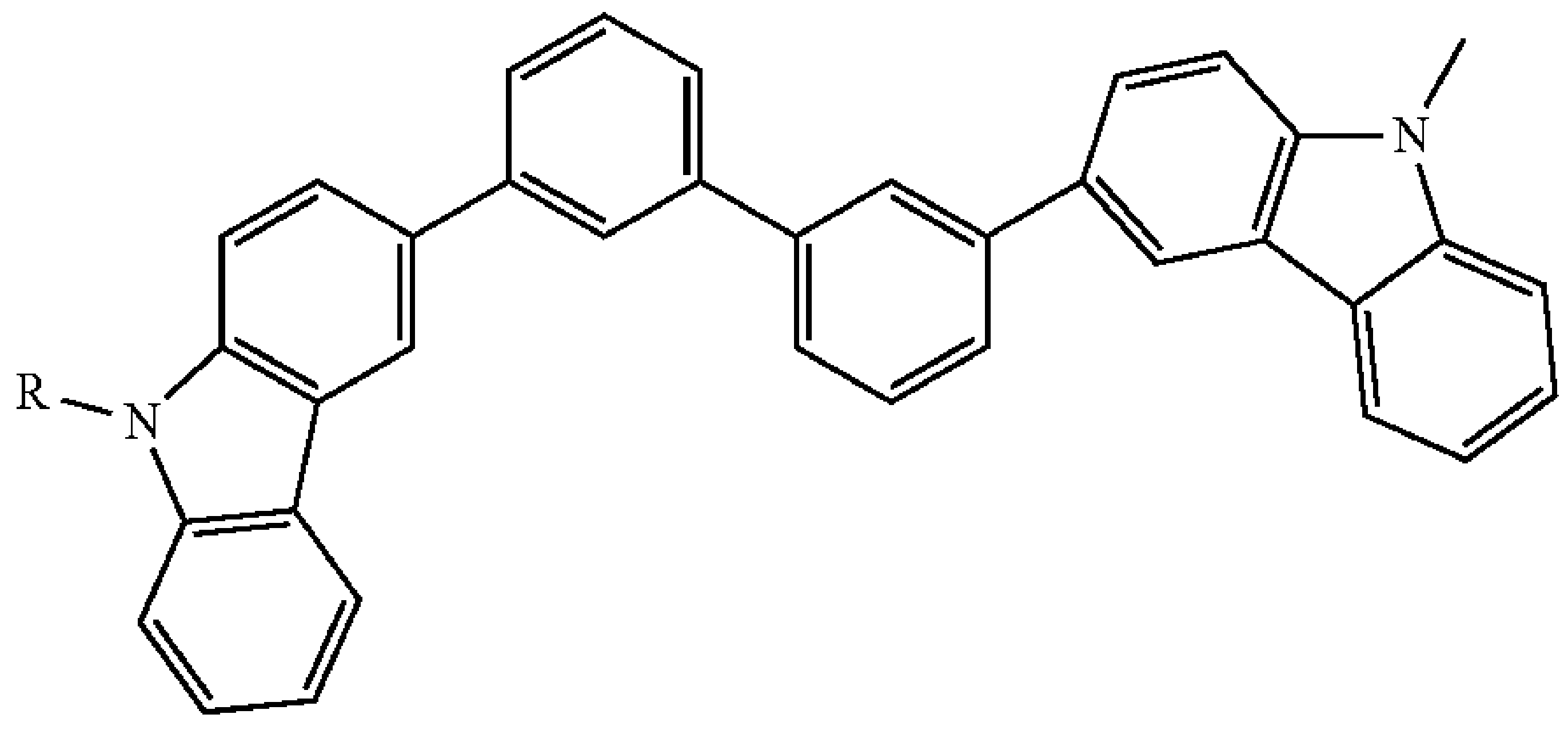

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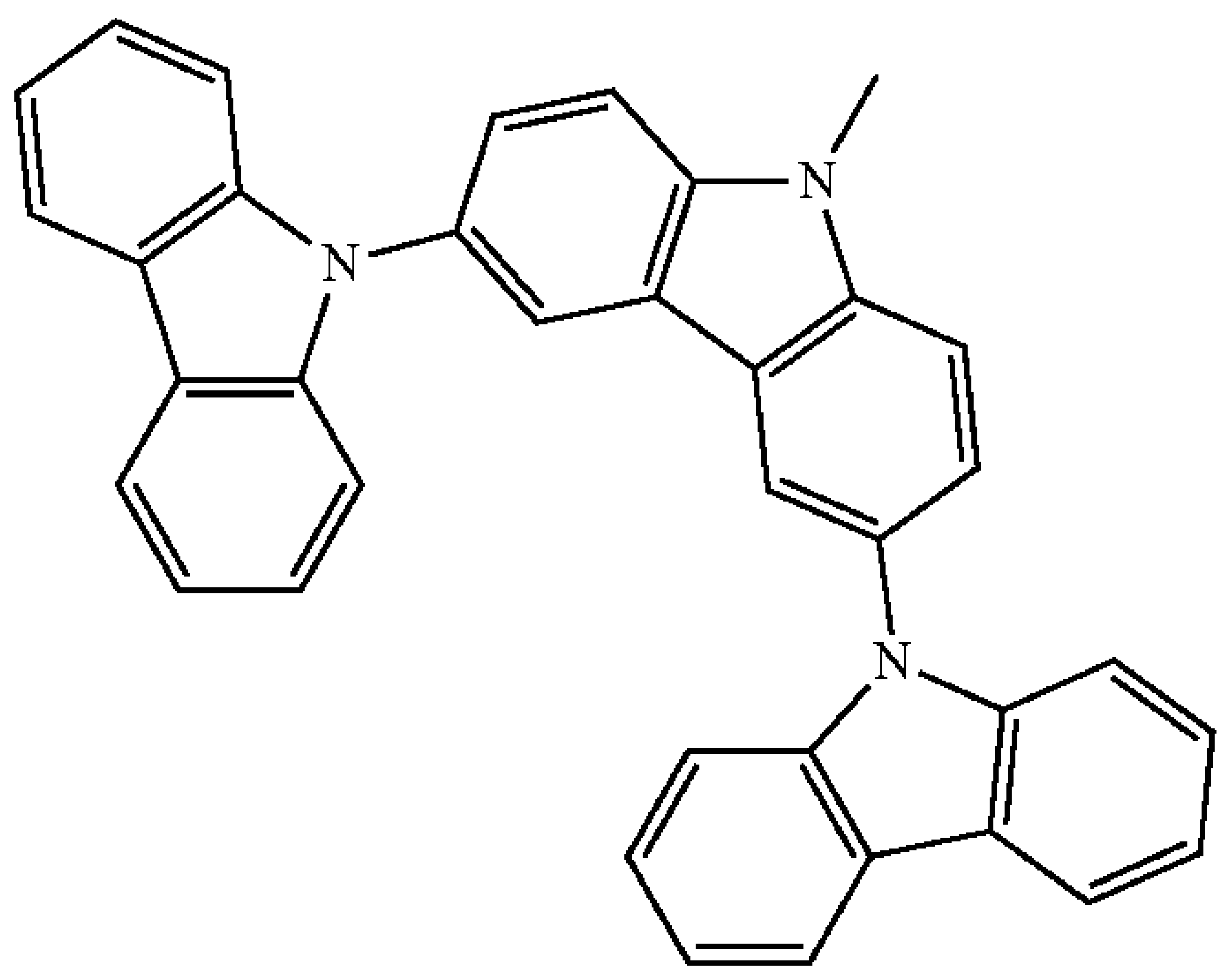

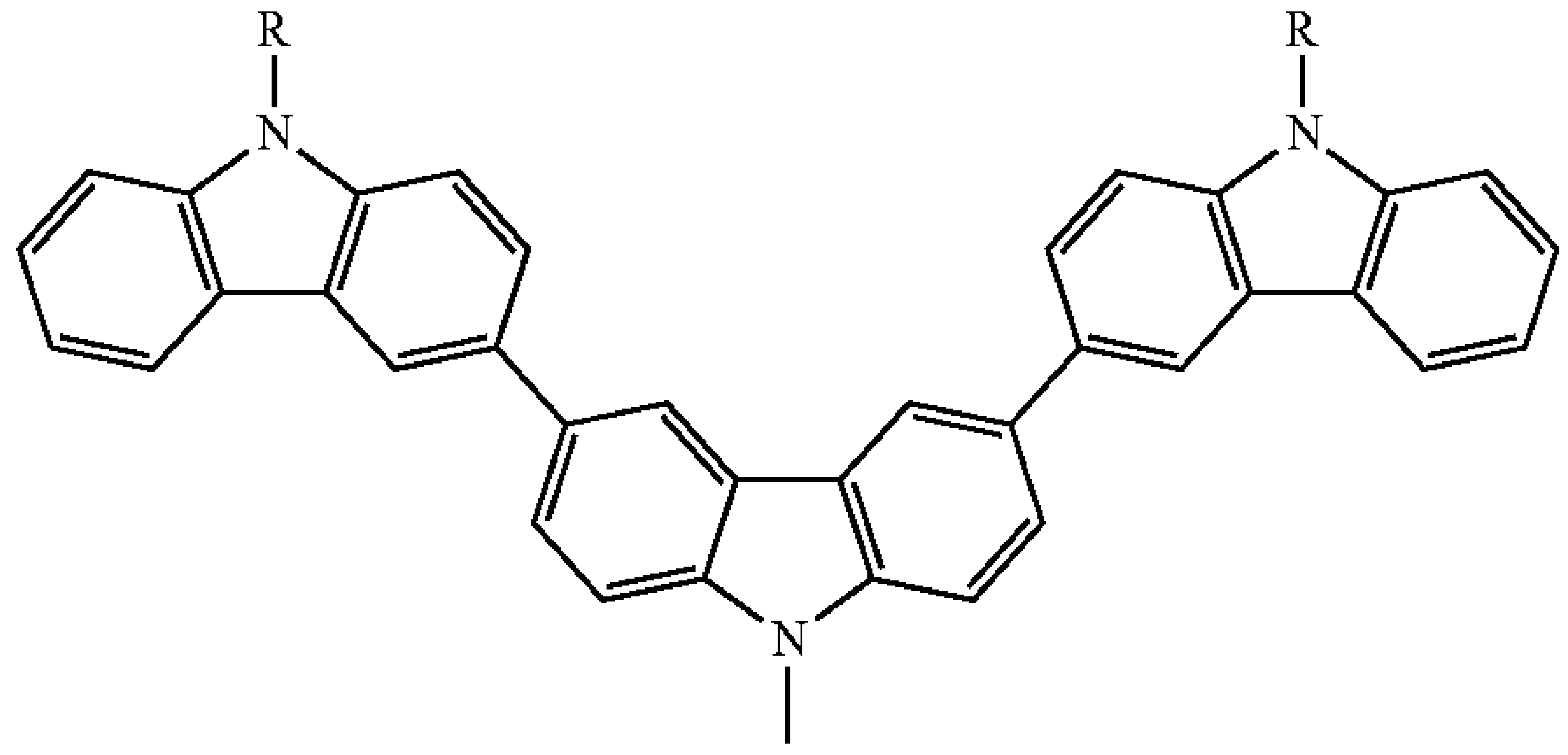

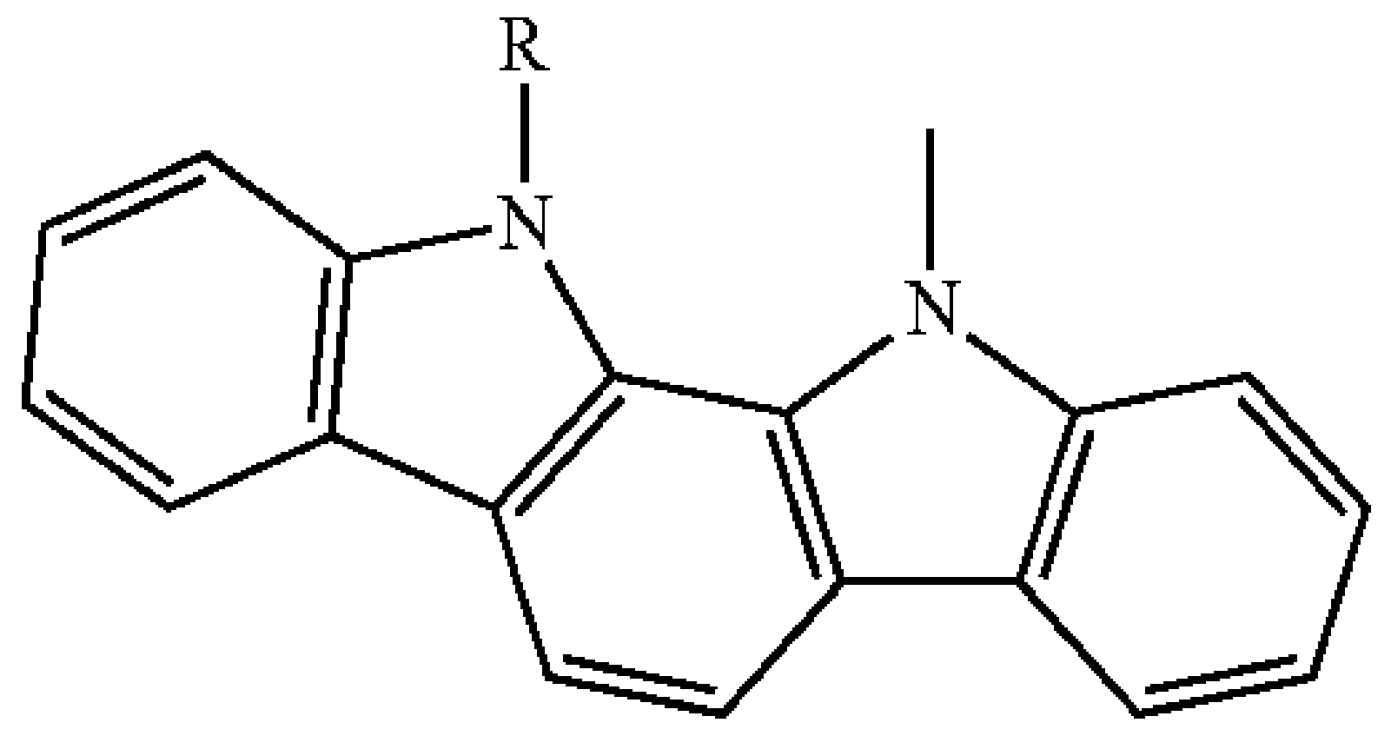

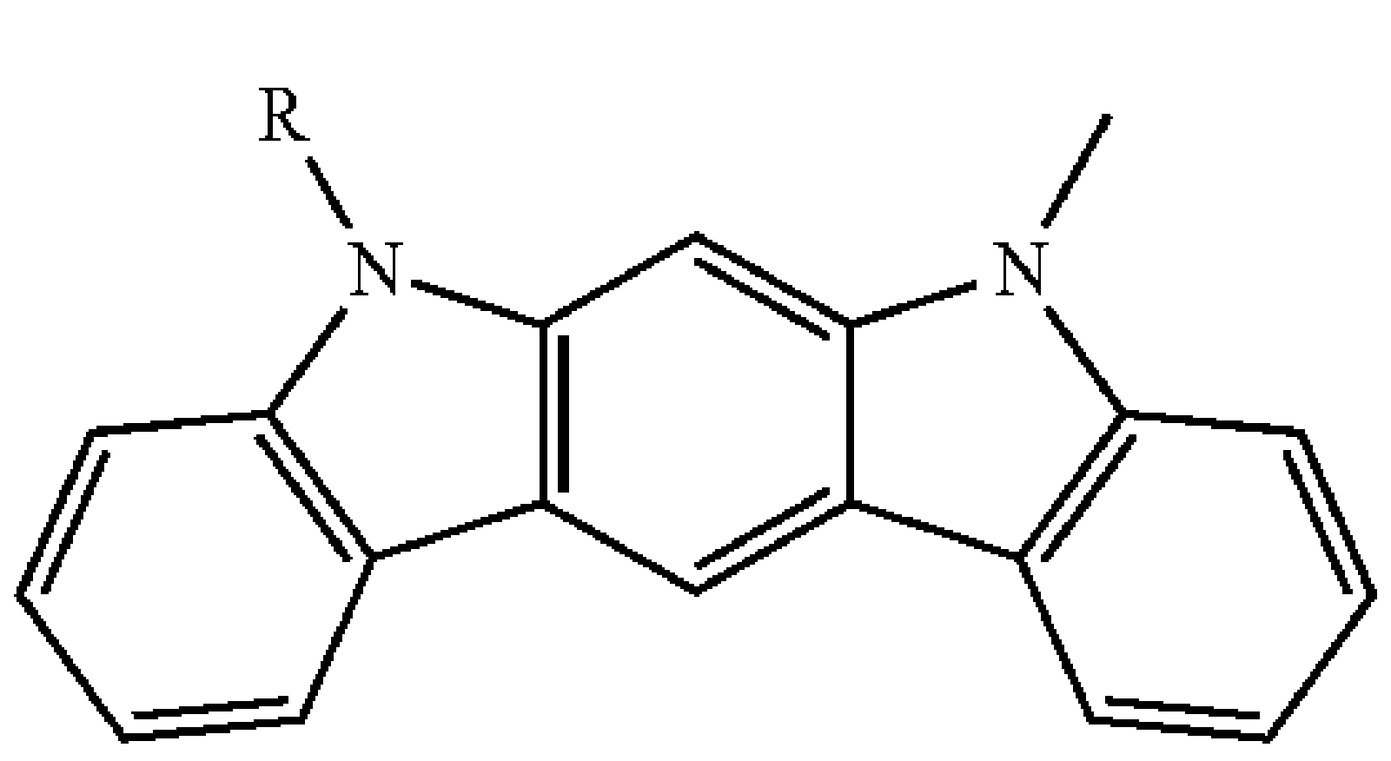

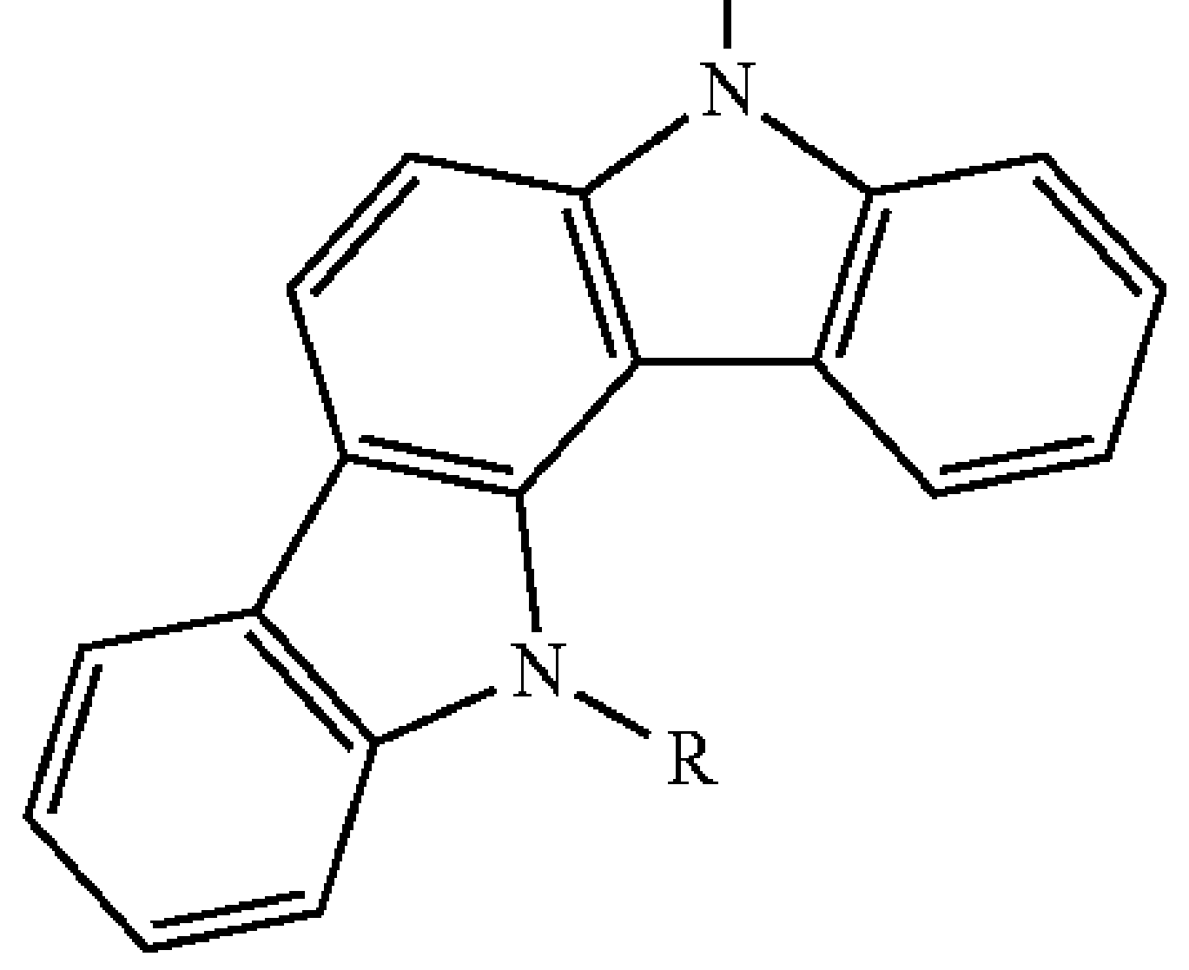

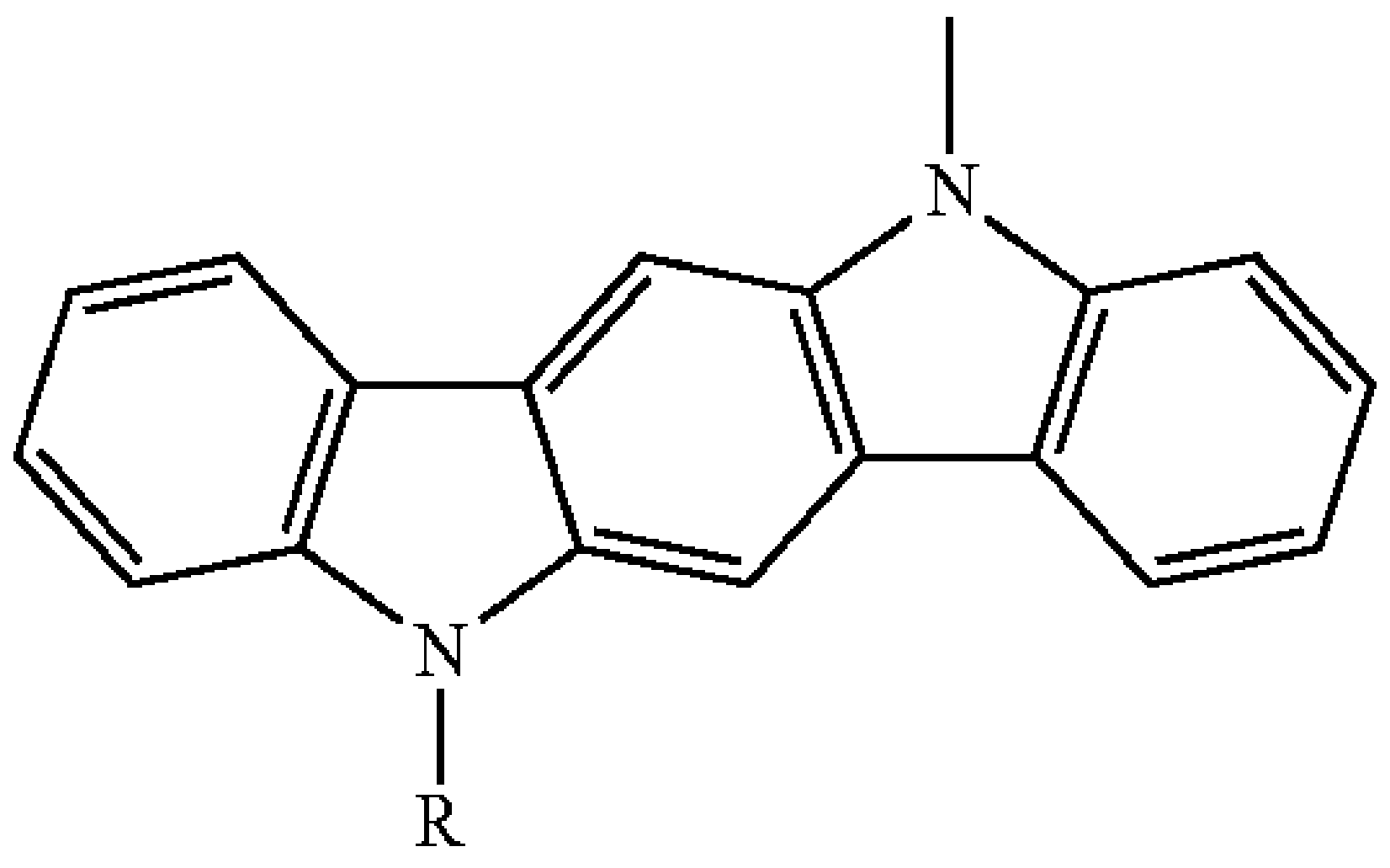

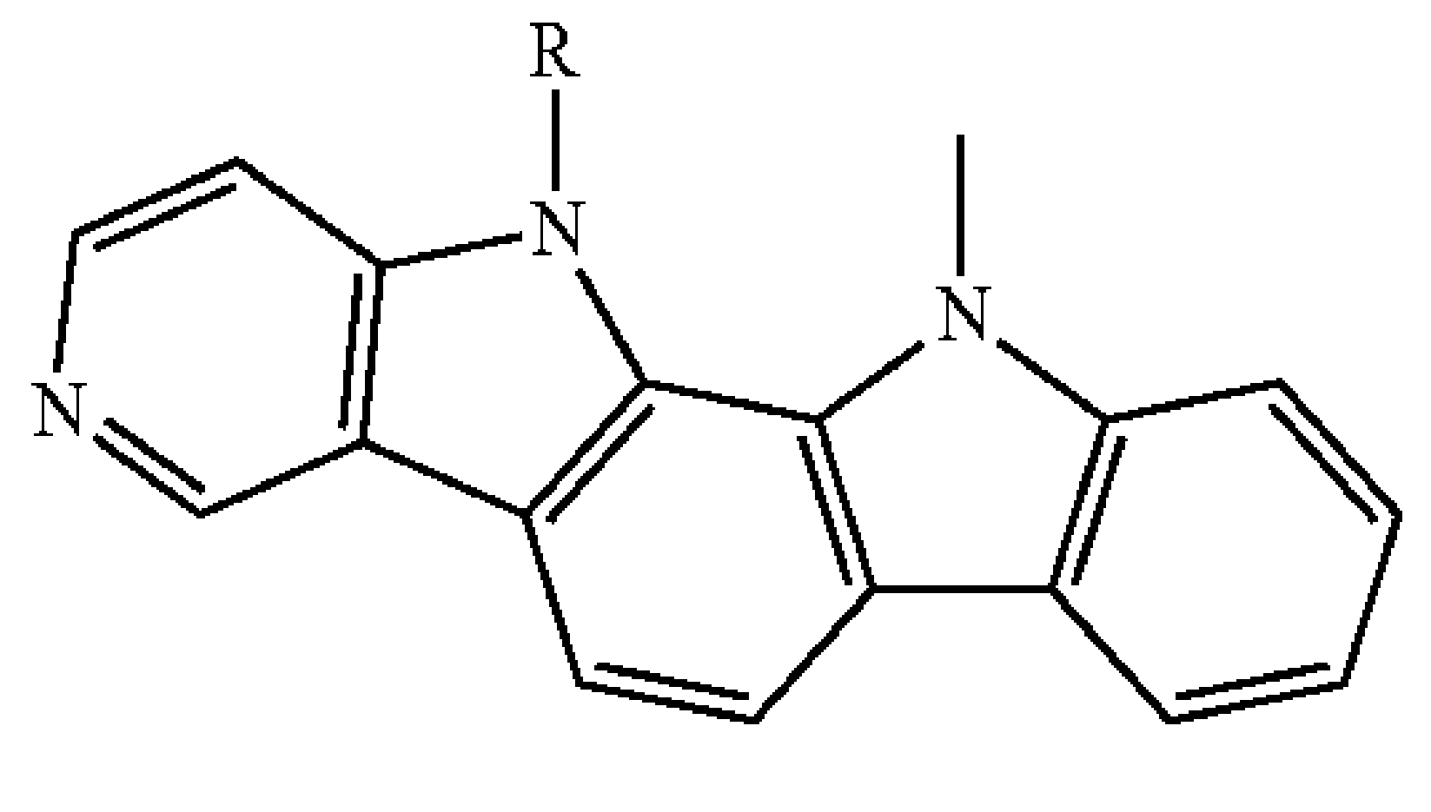

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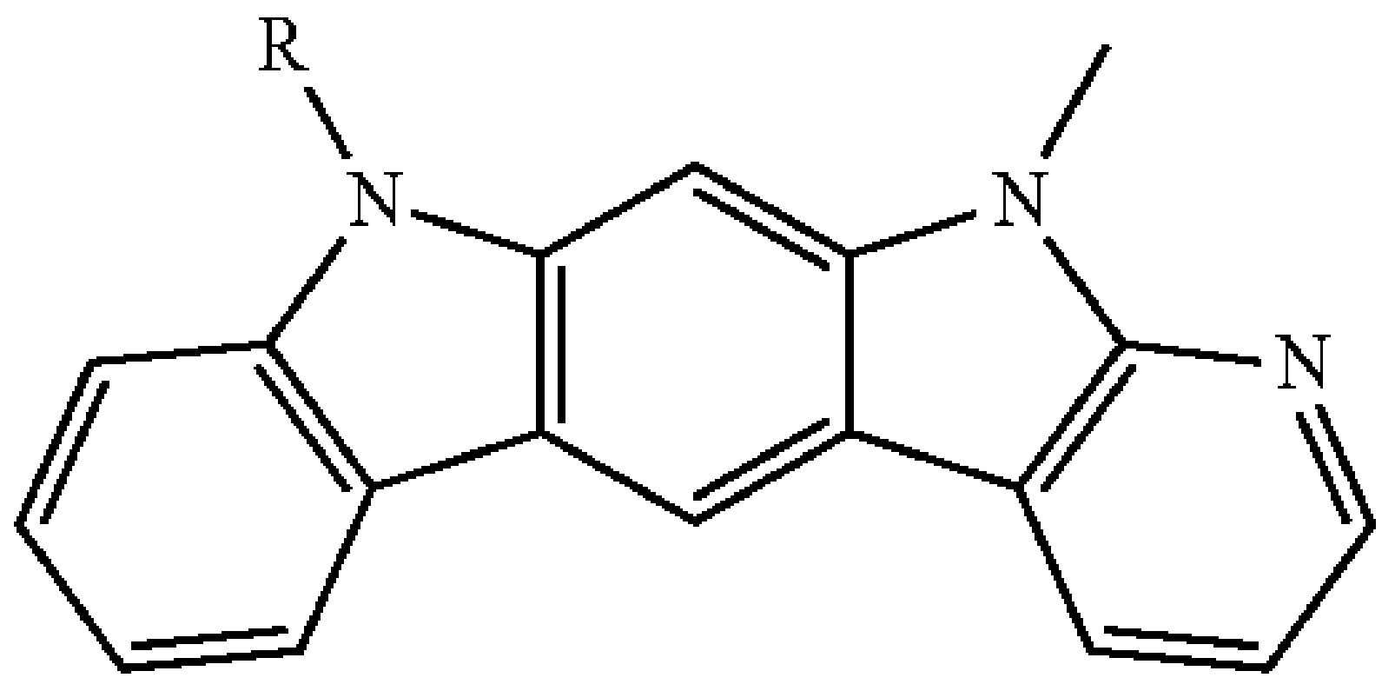

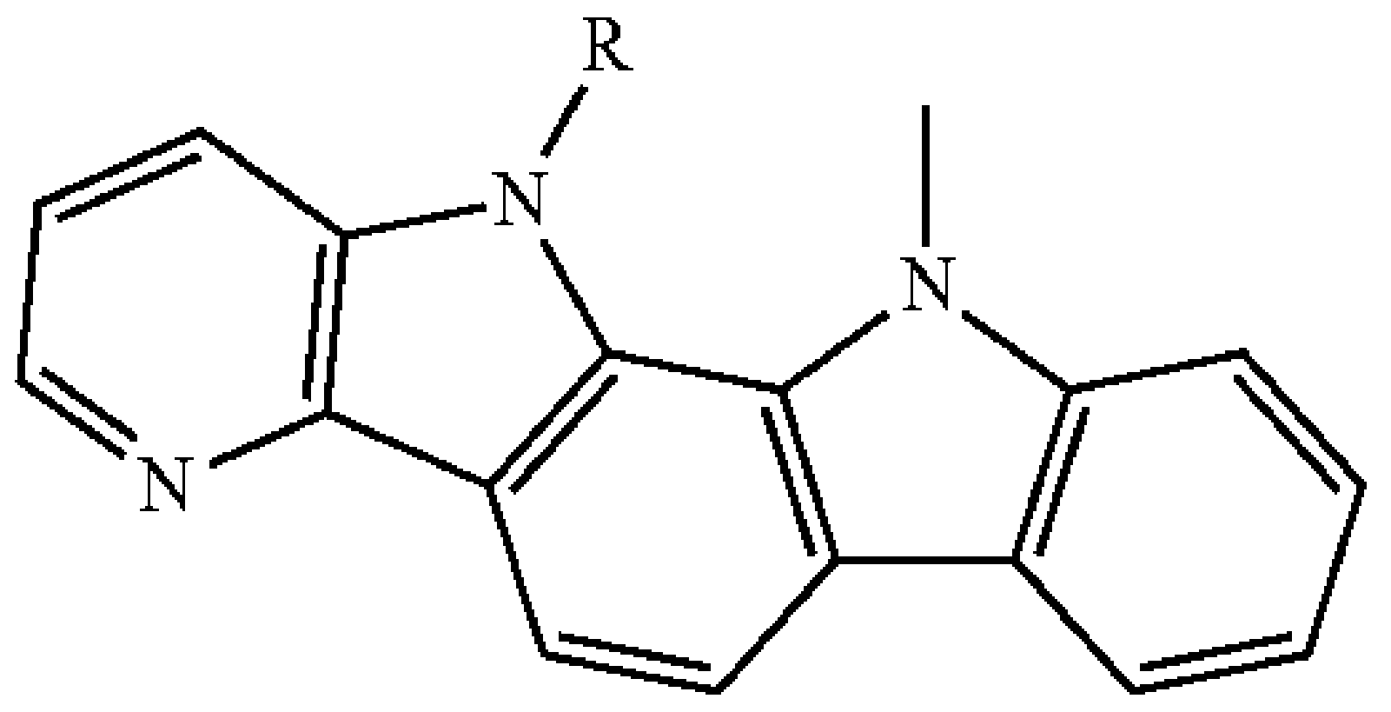

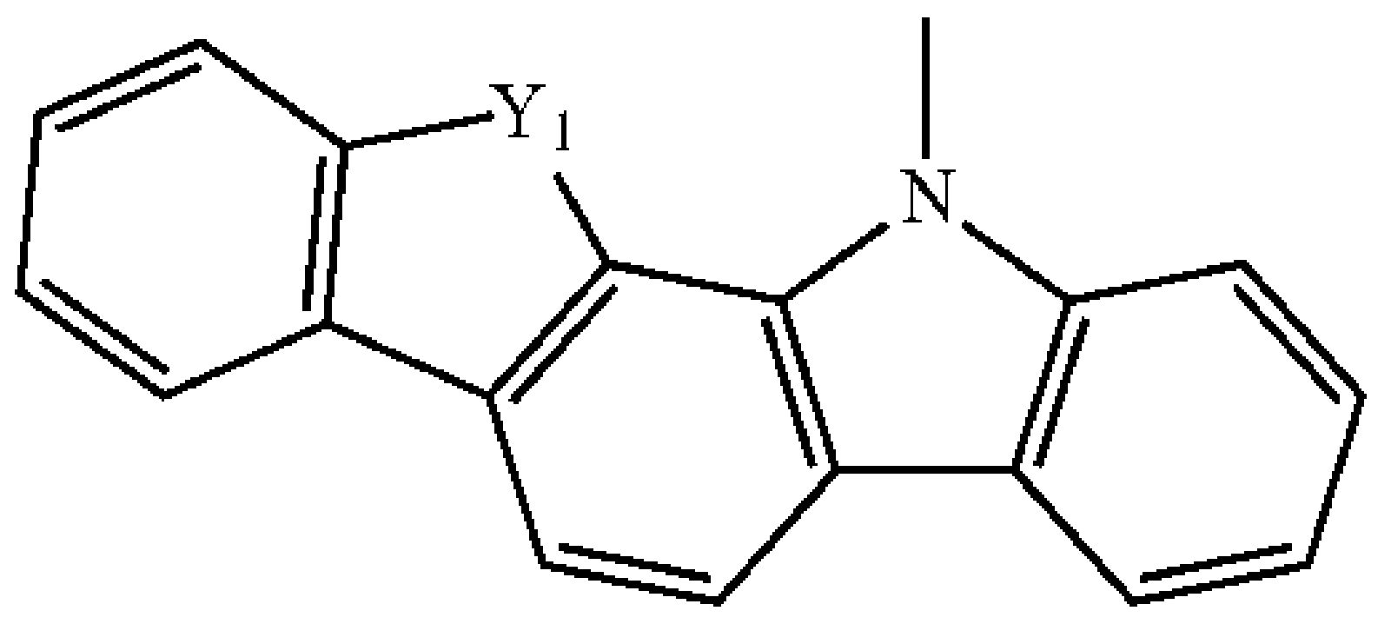

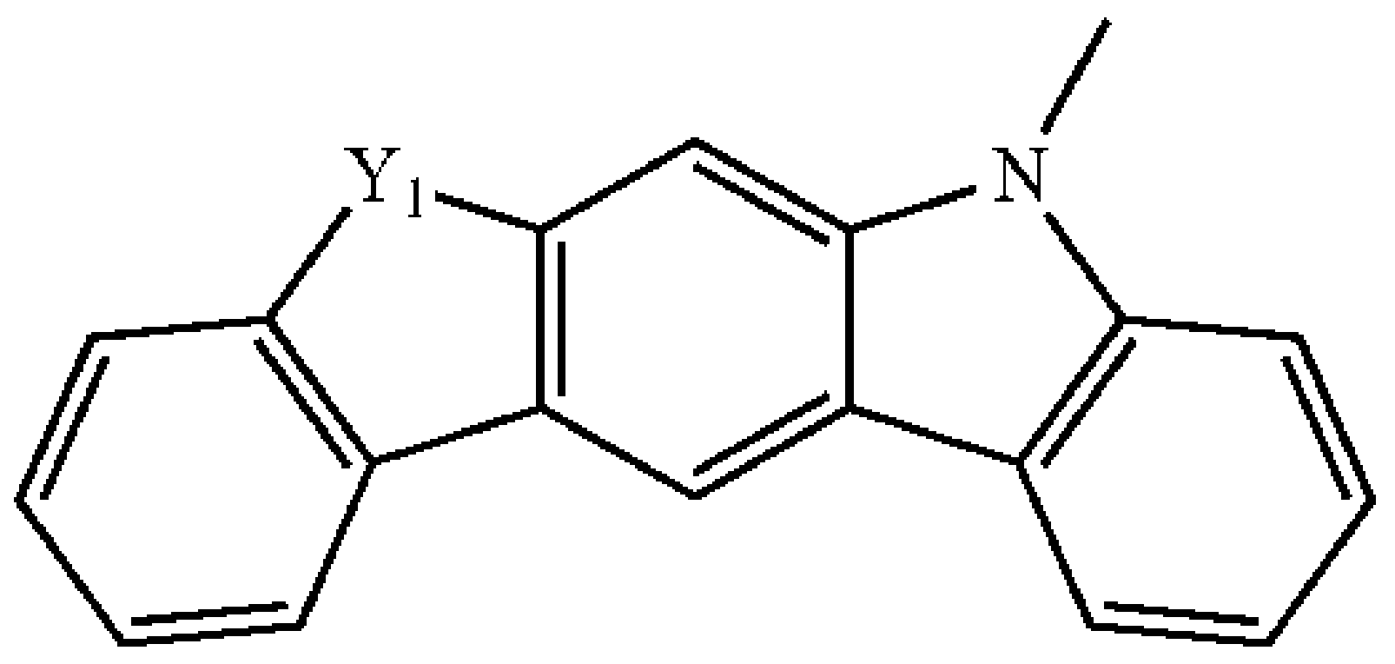

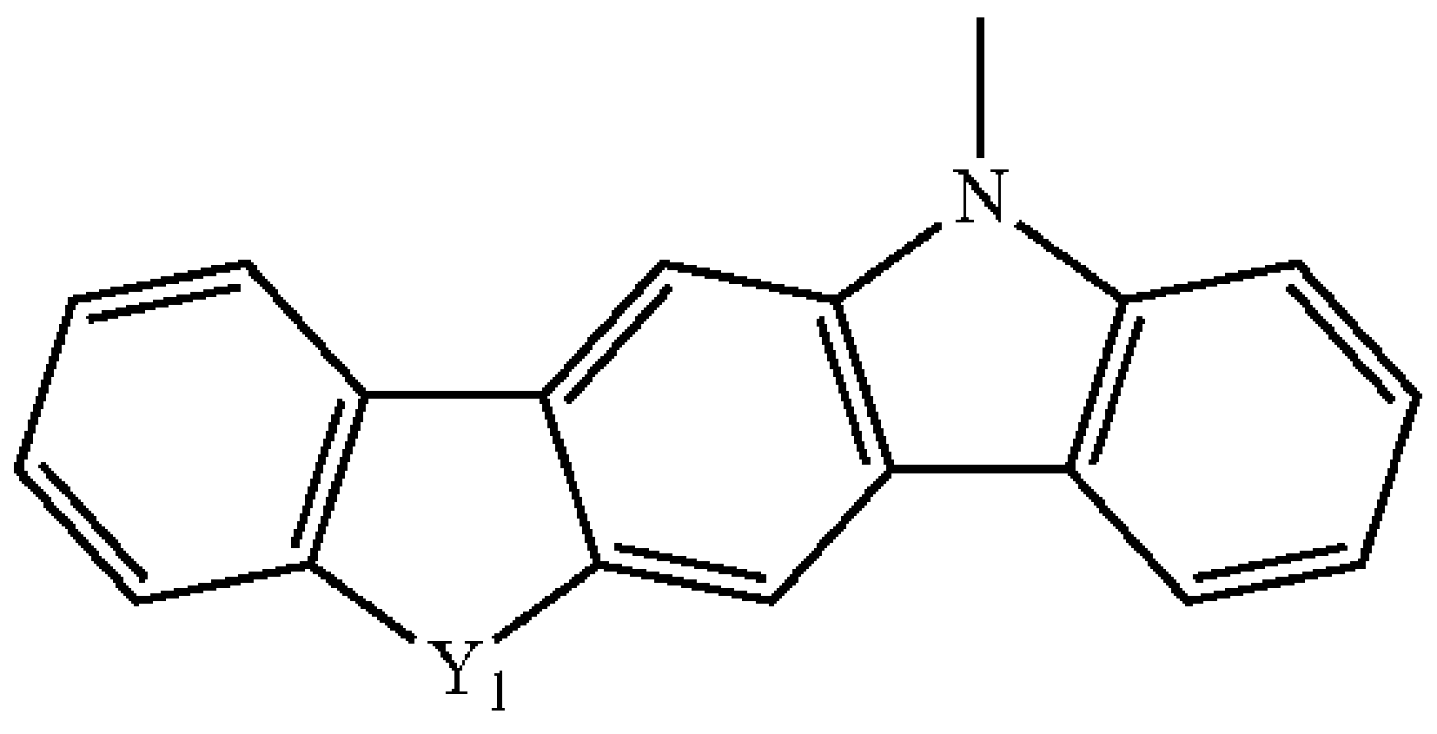

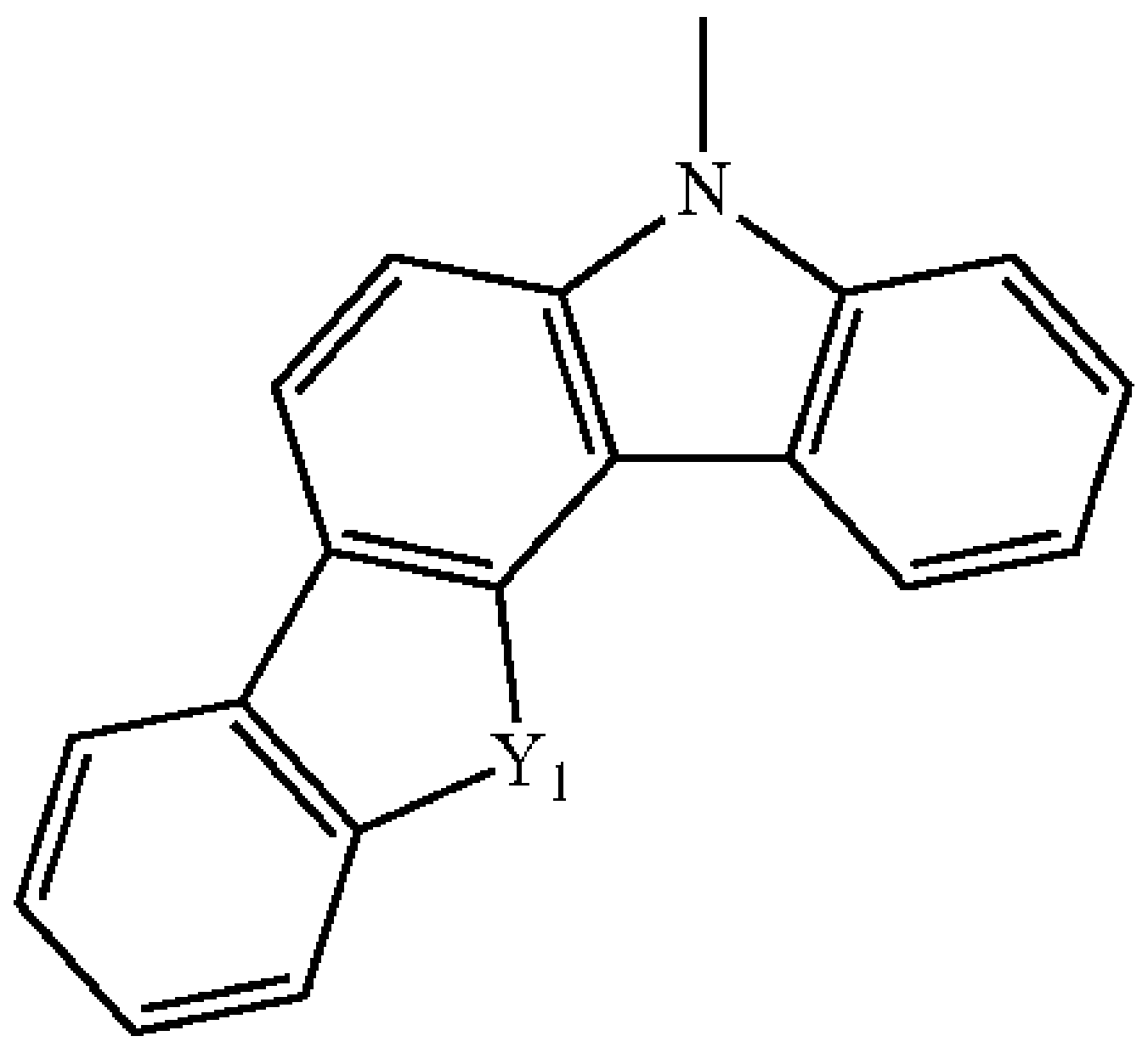

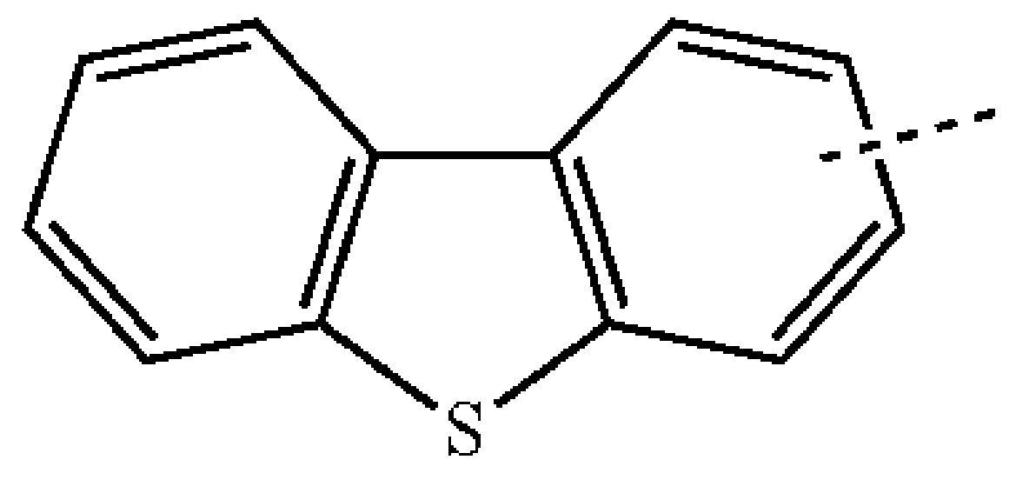

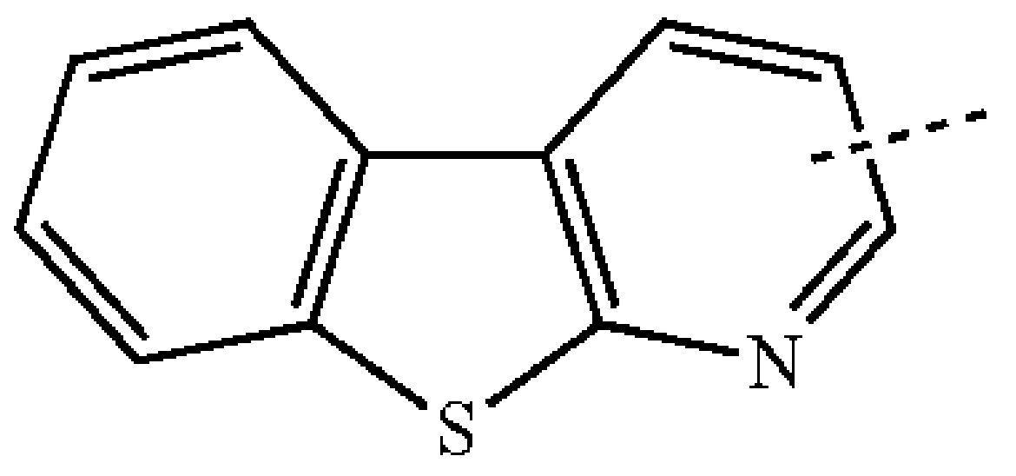

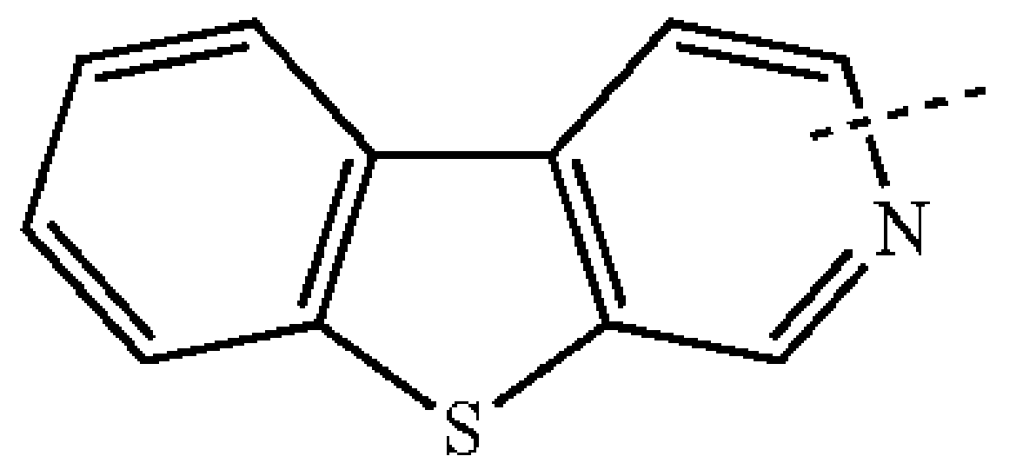

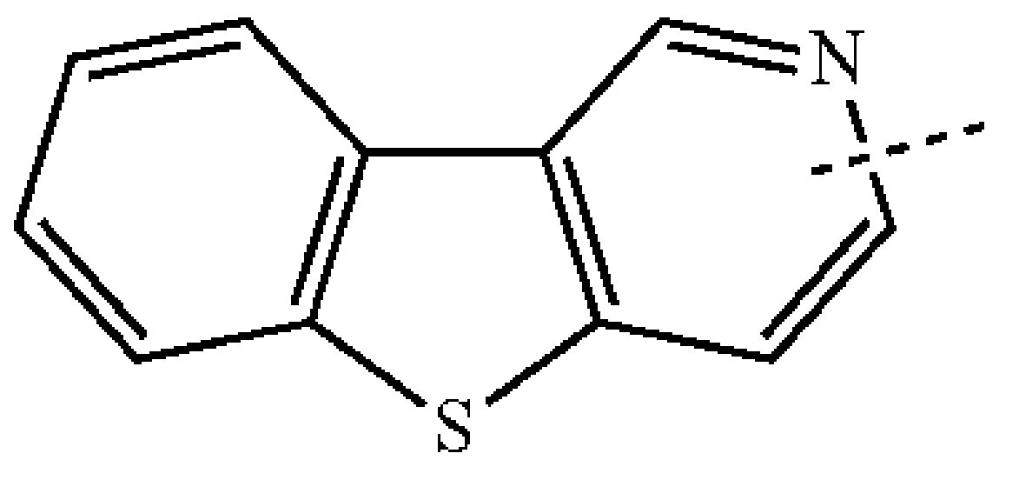

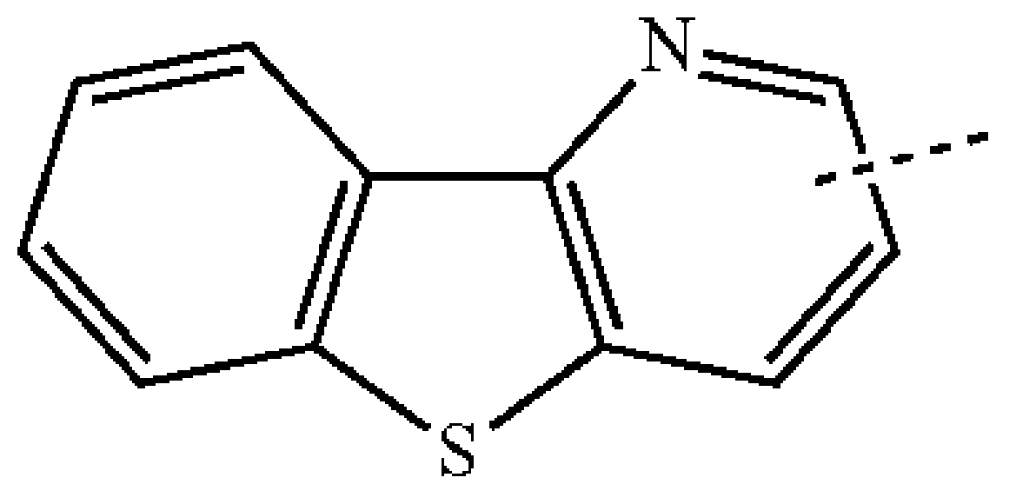

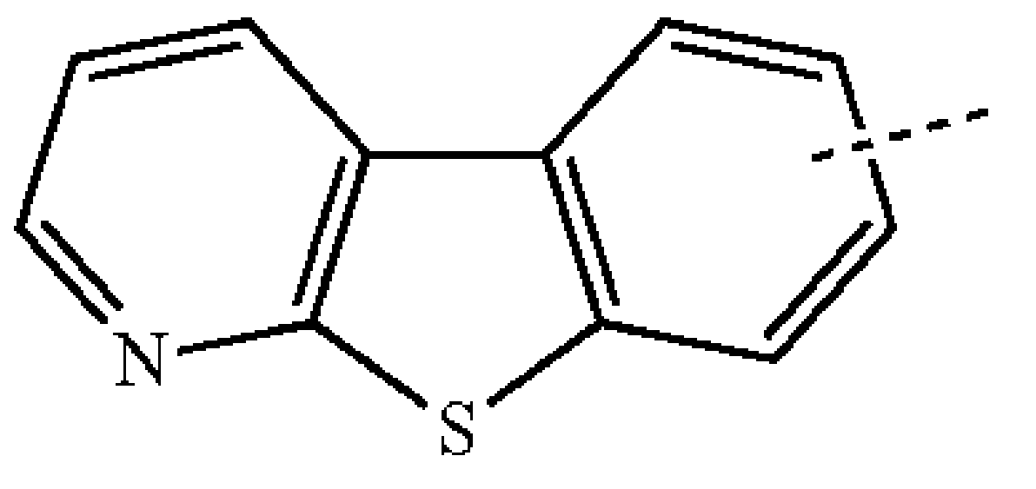

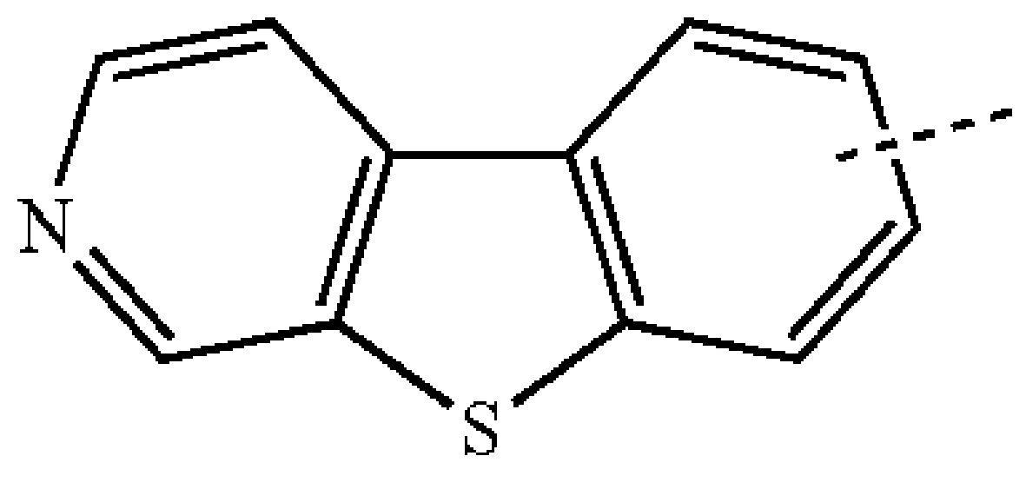

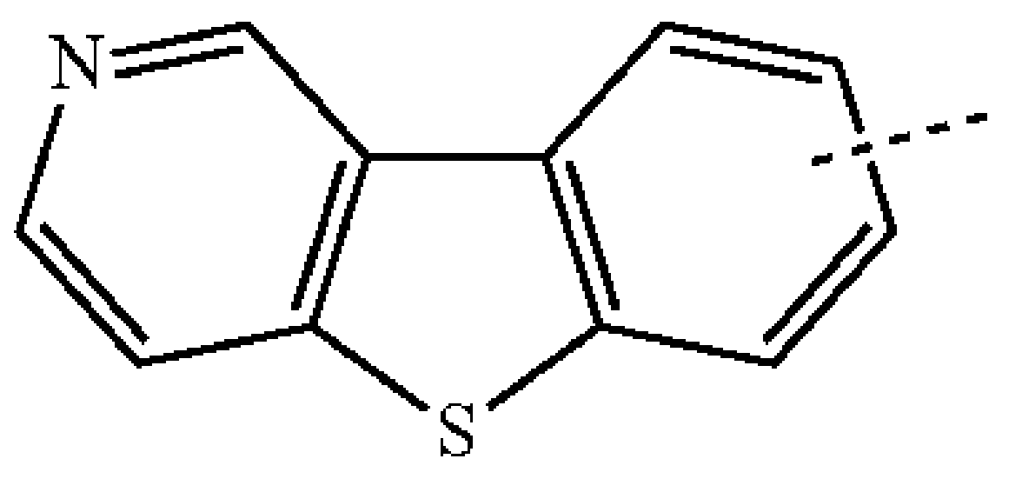

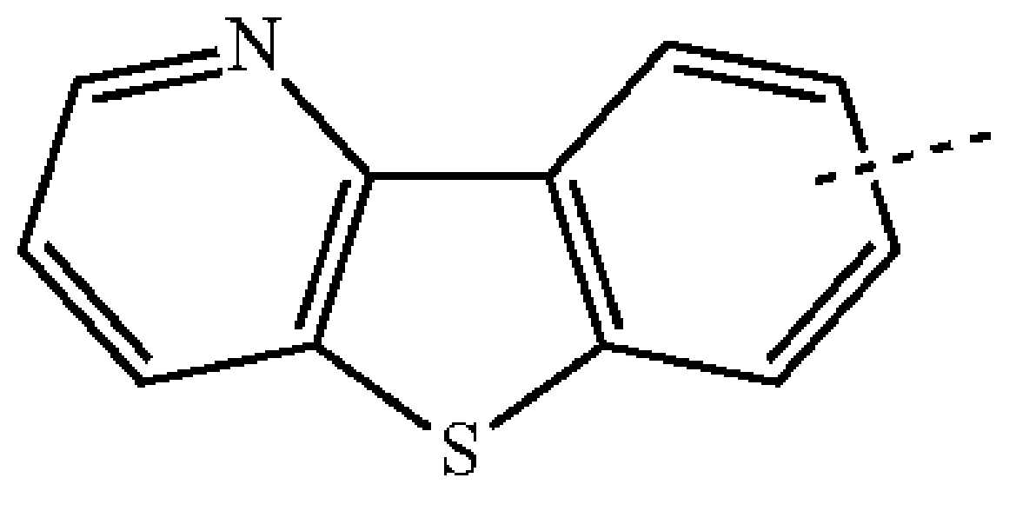

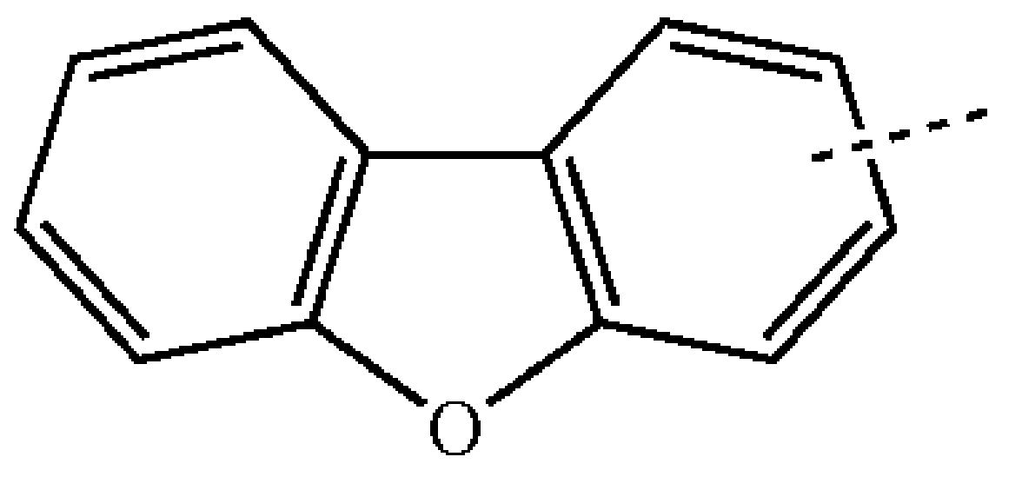

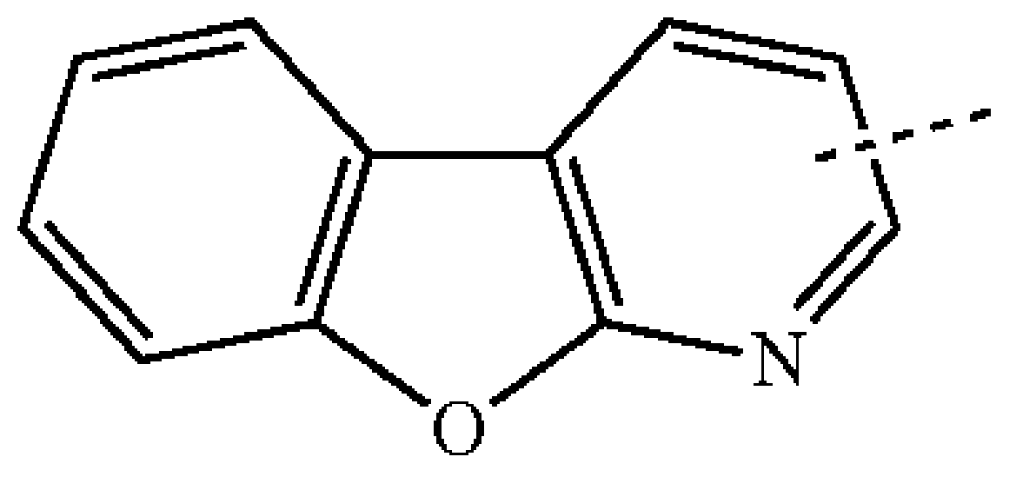

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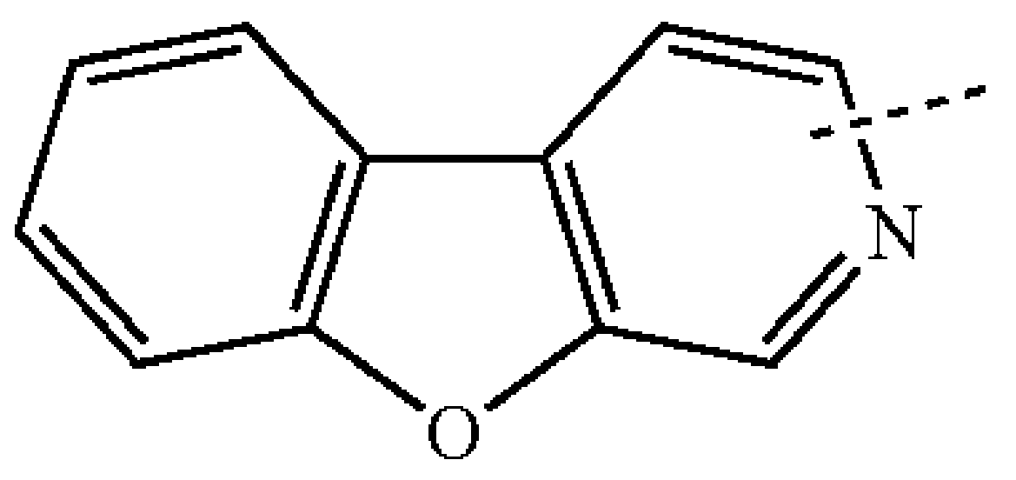
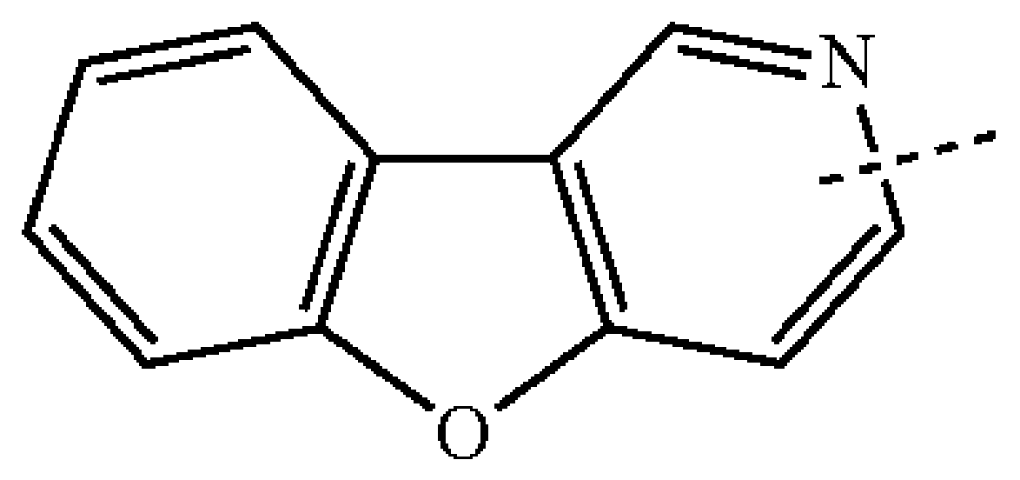
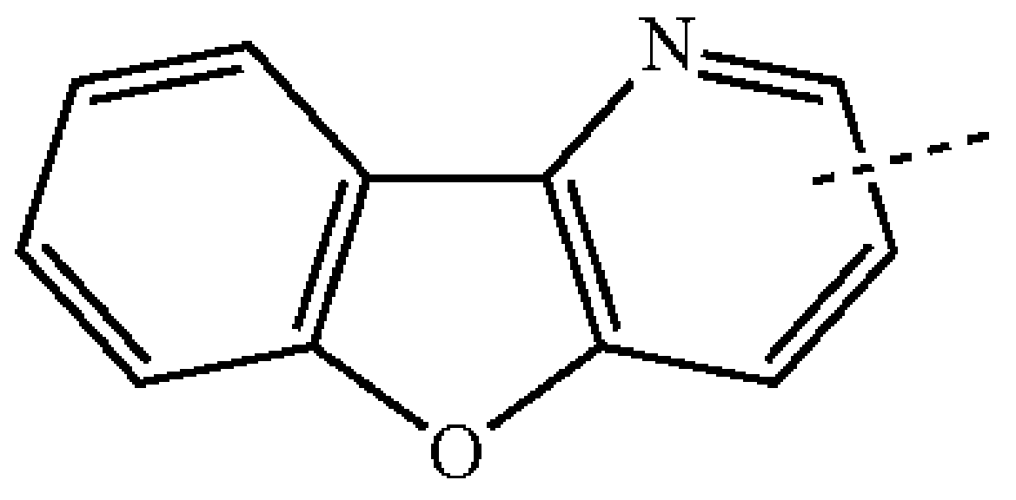
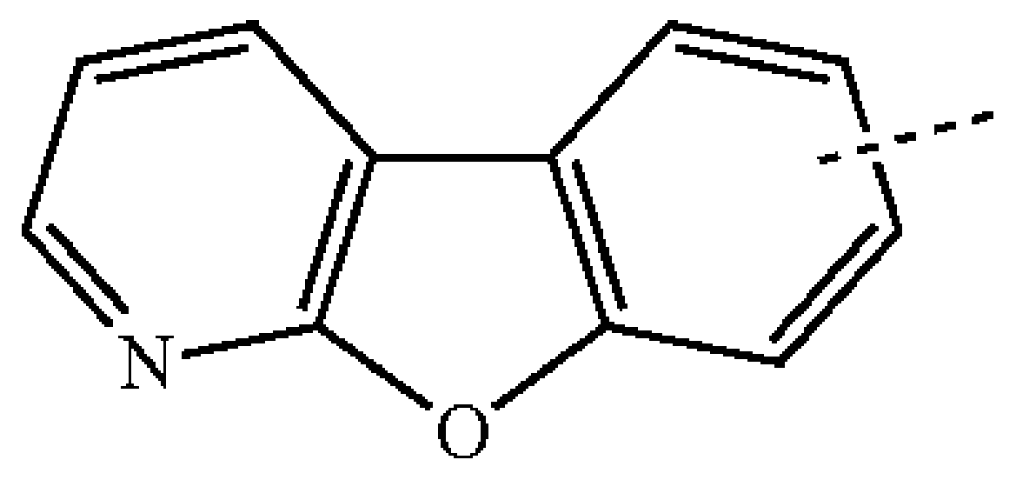
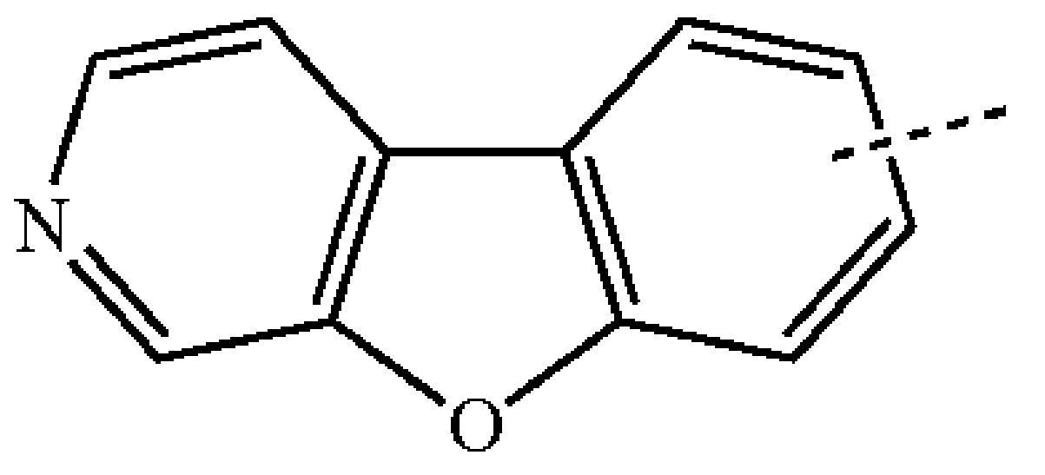
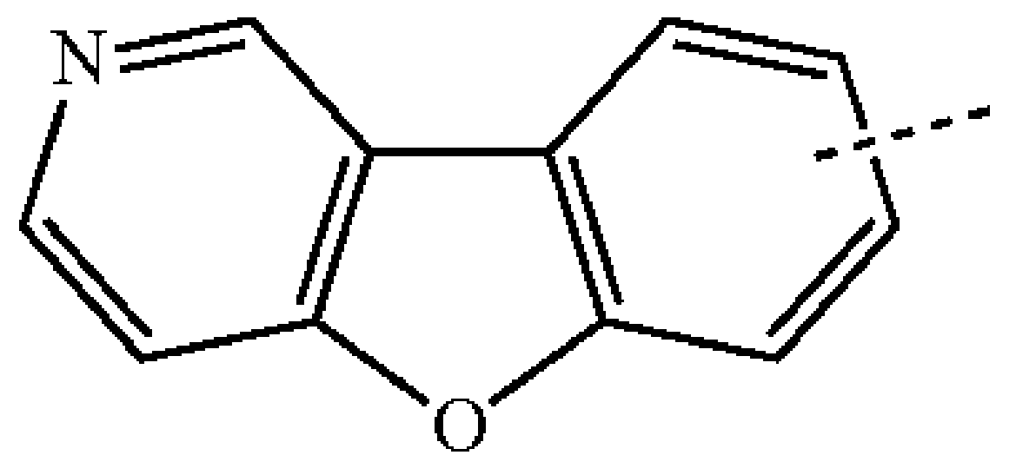
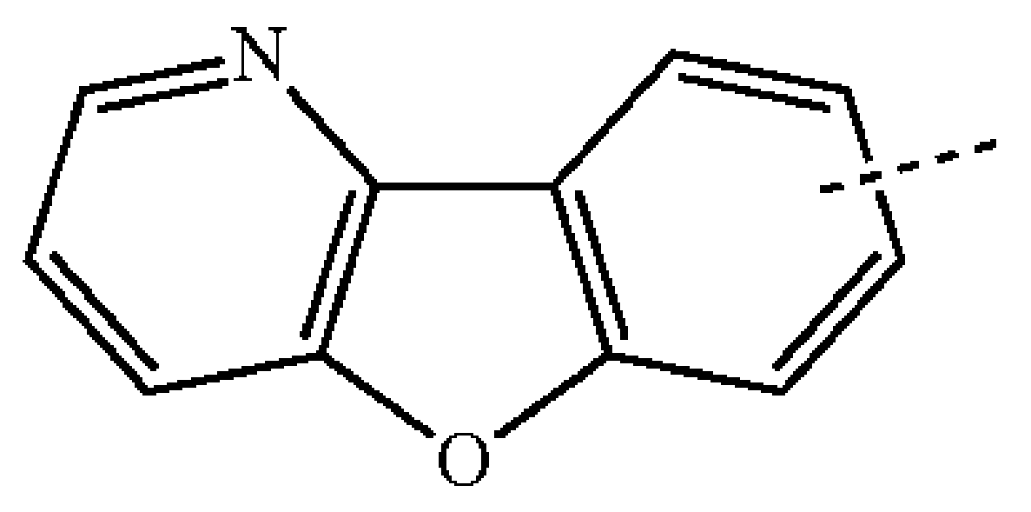
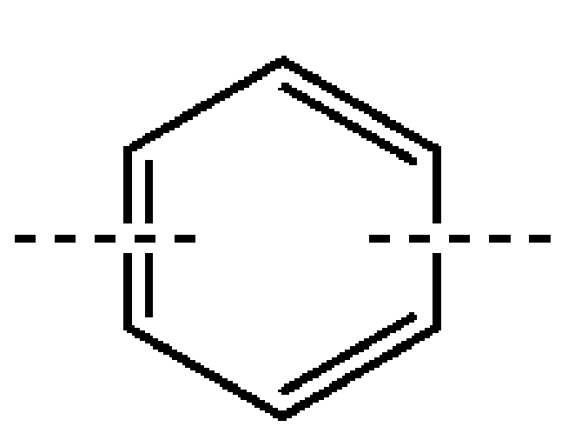
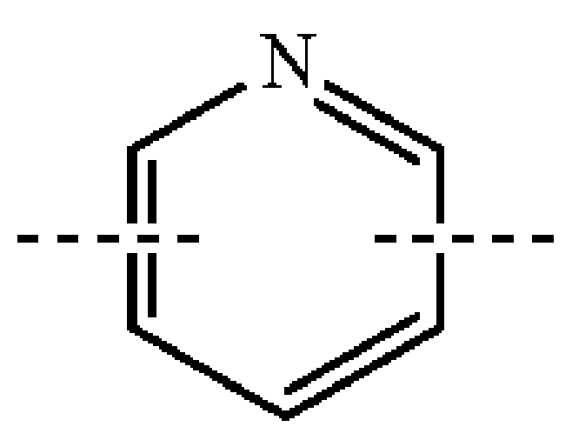
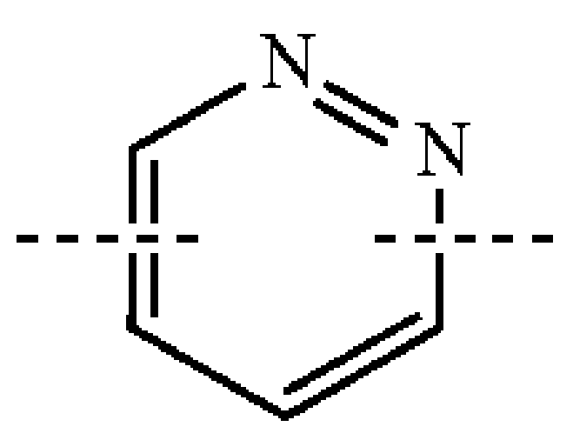
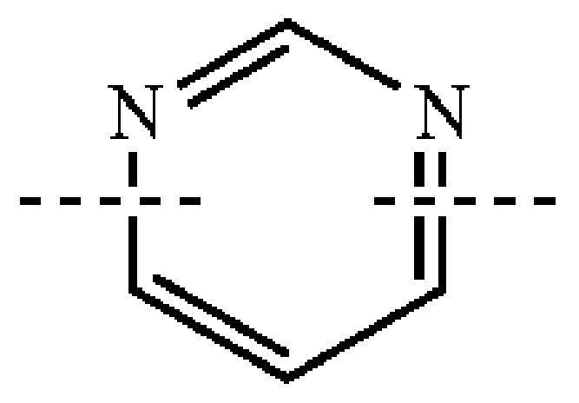
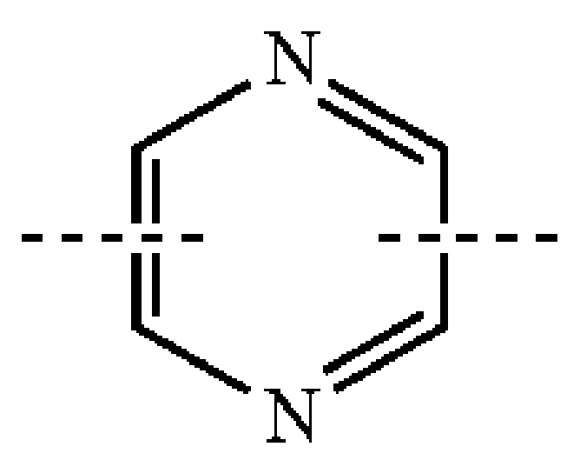
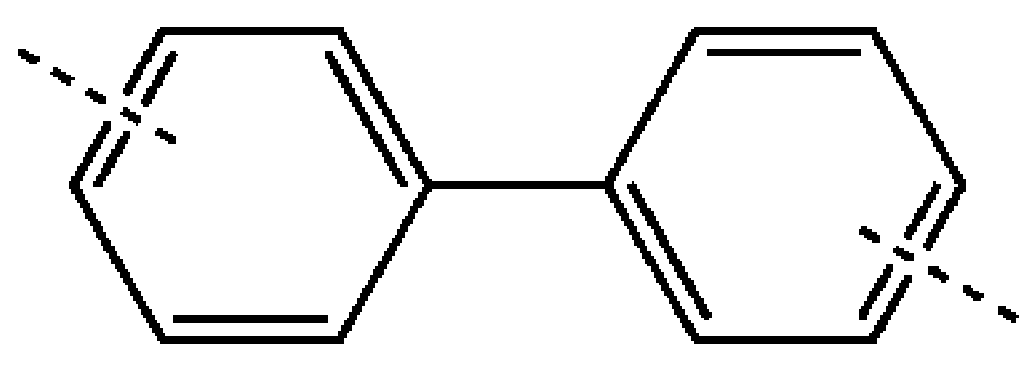
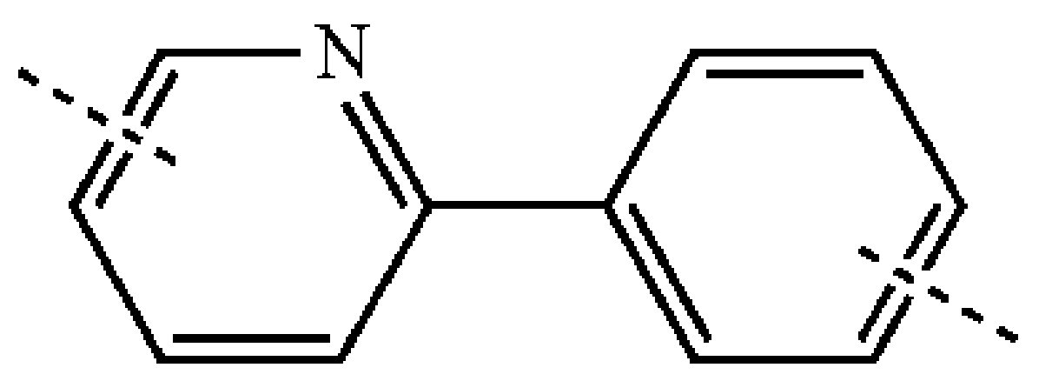
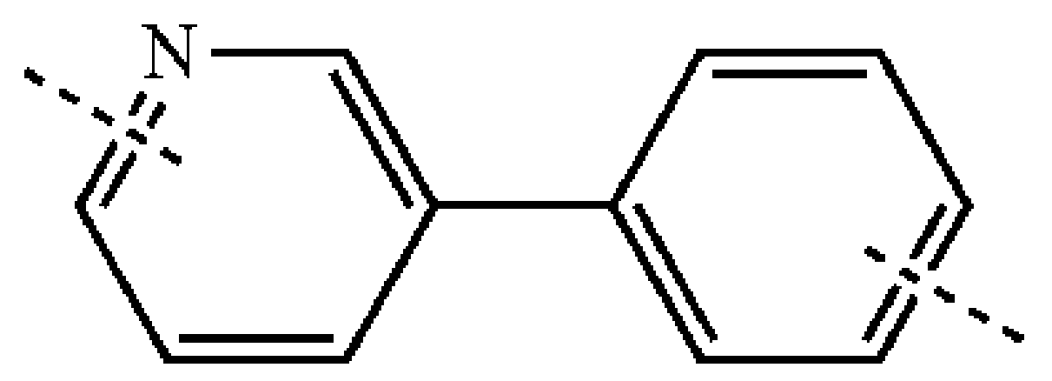
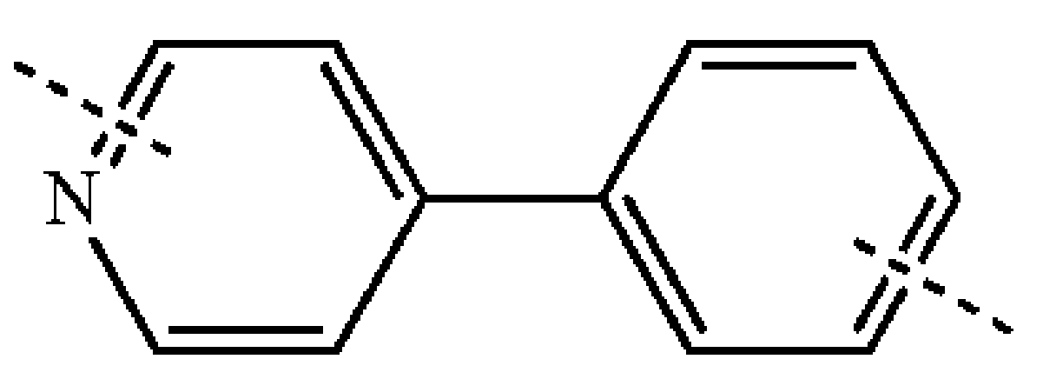
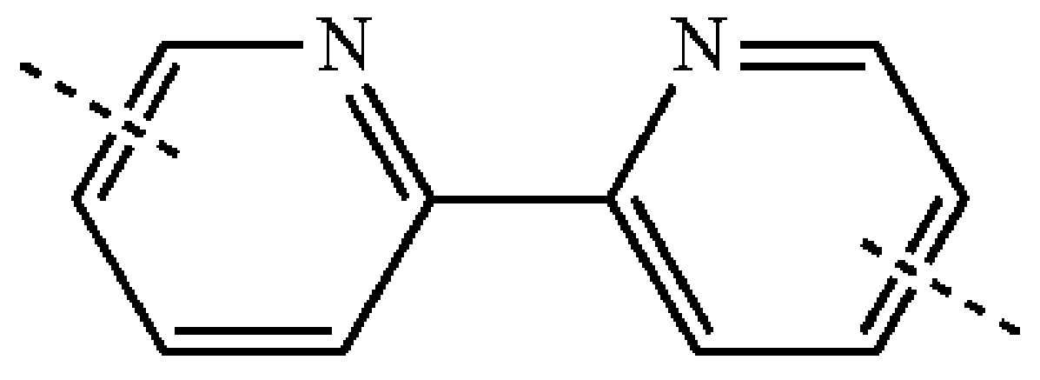
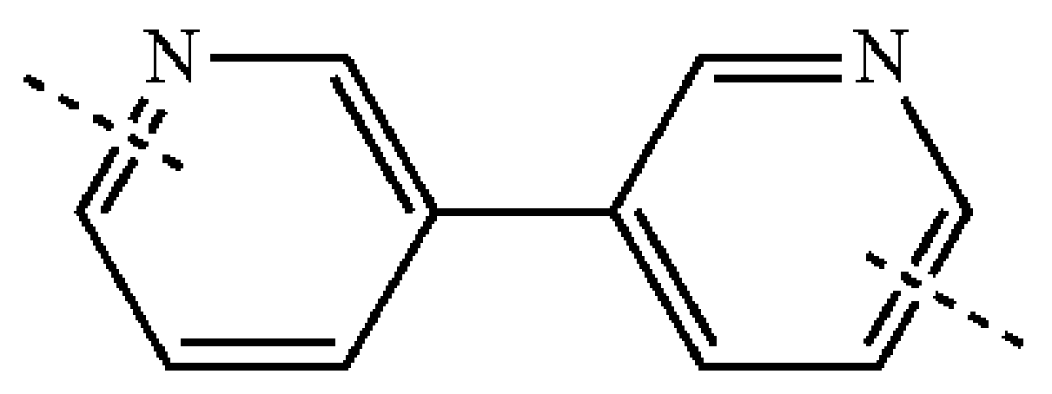
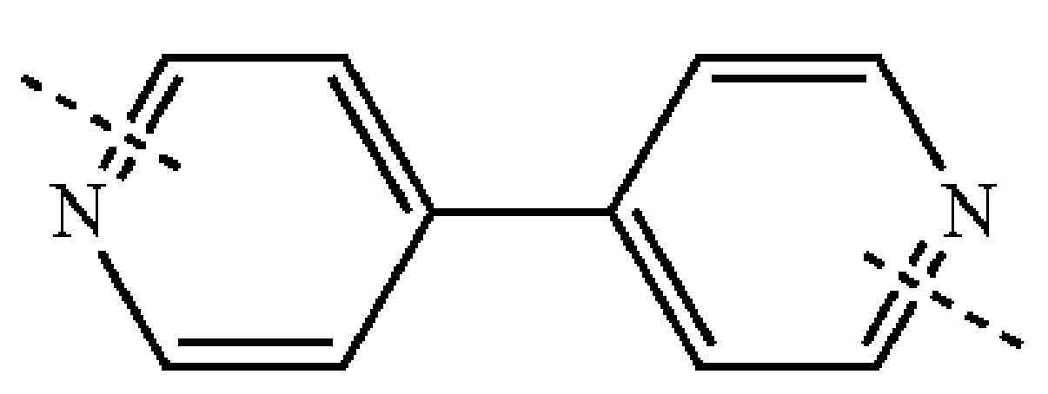
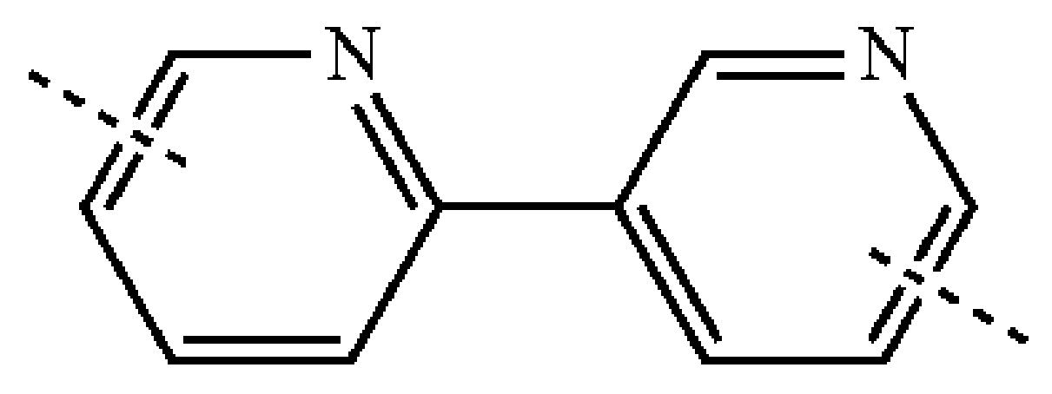
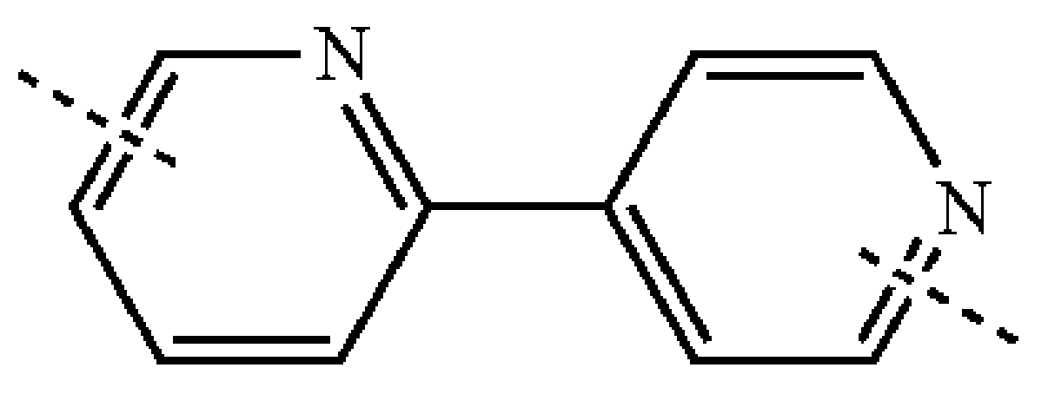
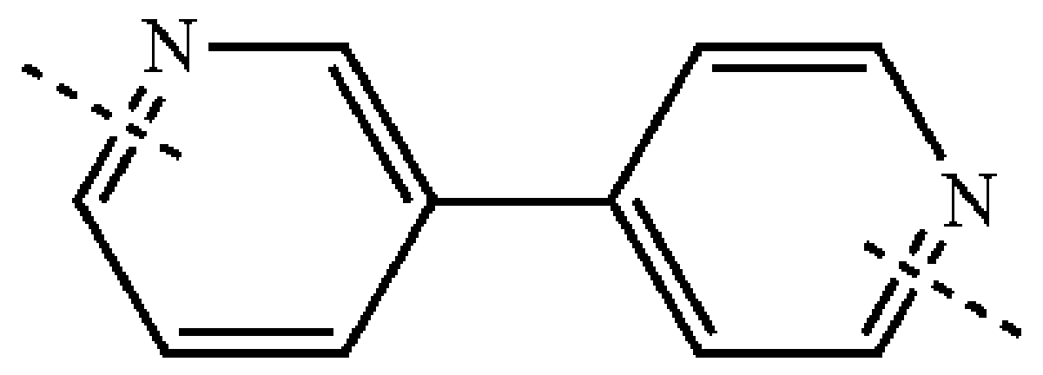
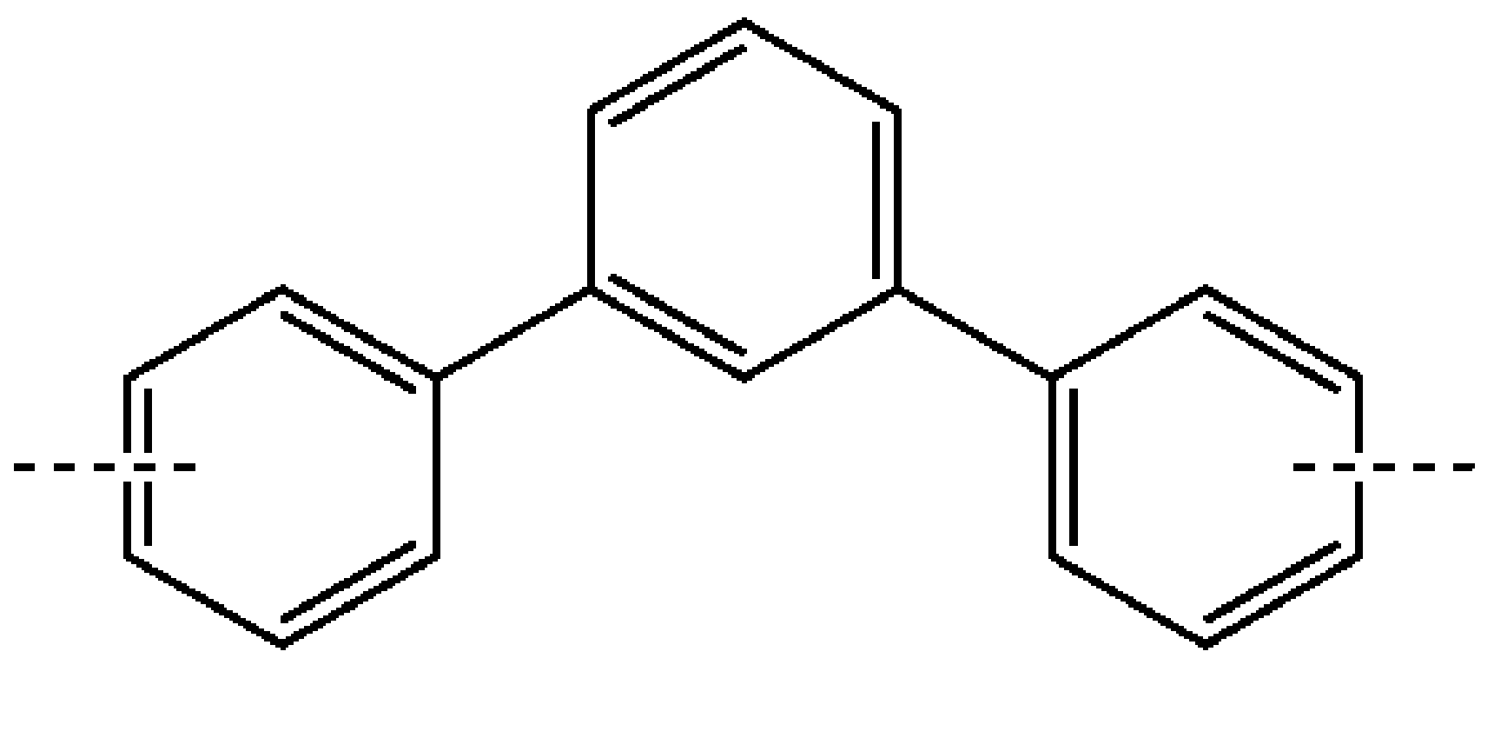








wherein Y_1 is selected from the group consisting of O, S, and Se, wherein R is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one embodiment, L is independently selected from the group consisting of:

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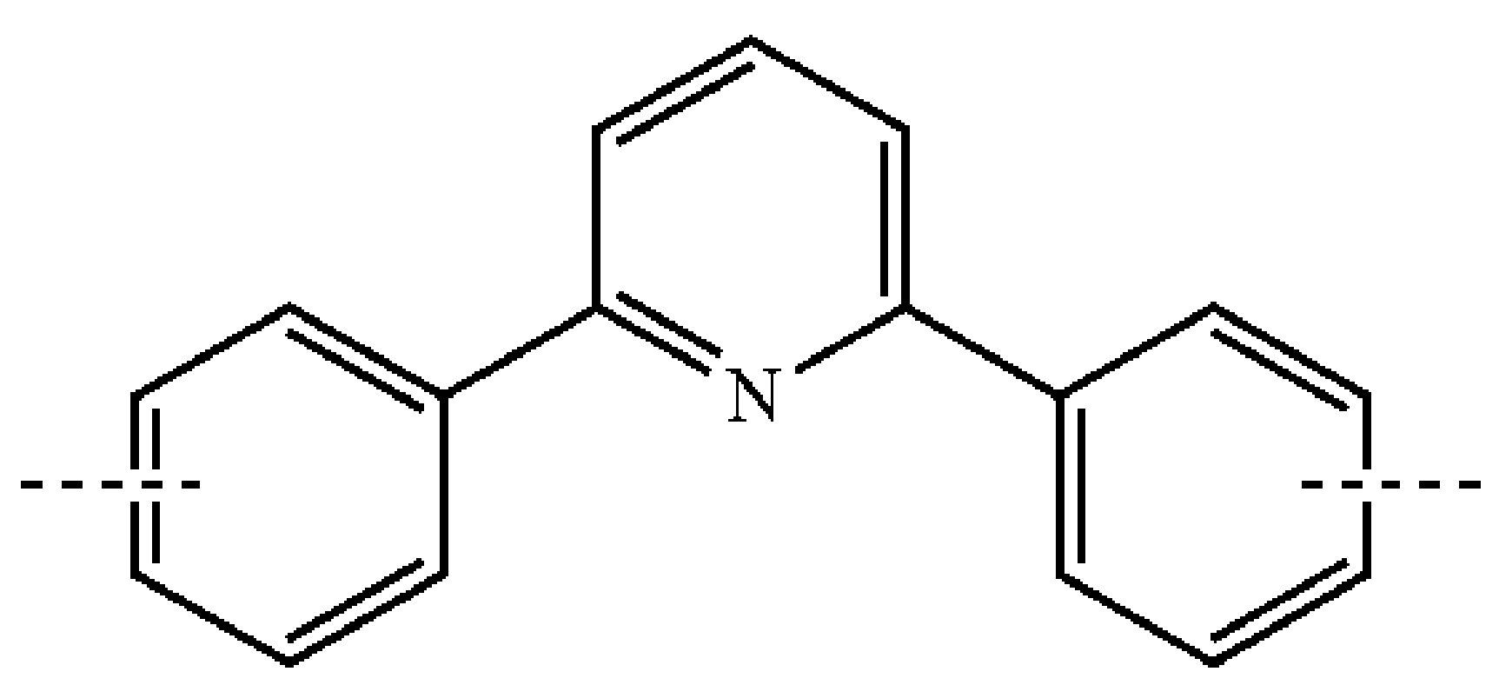
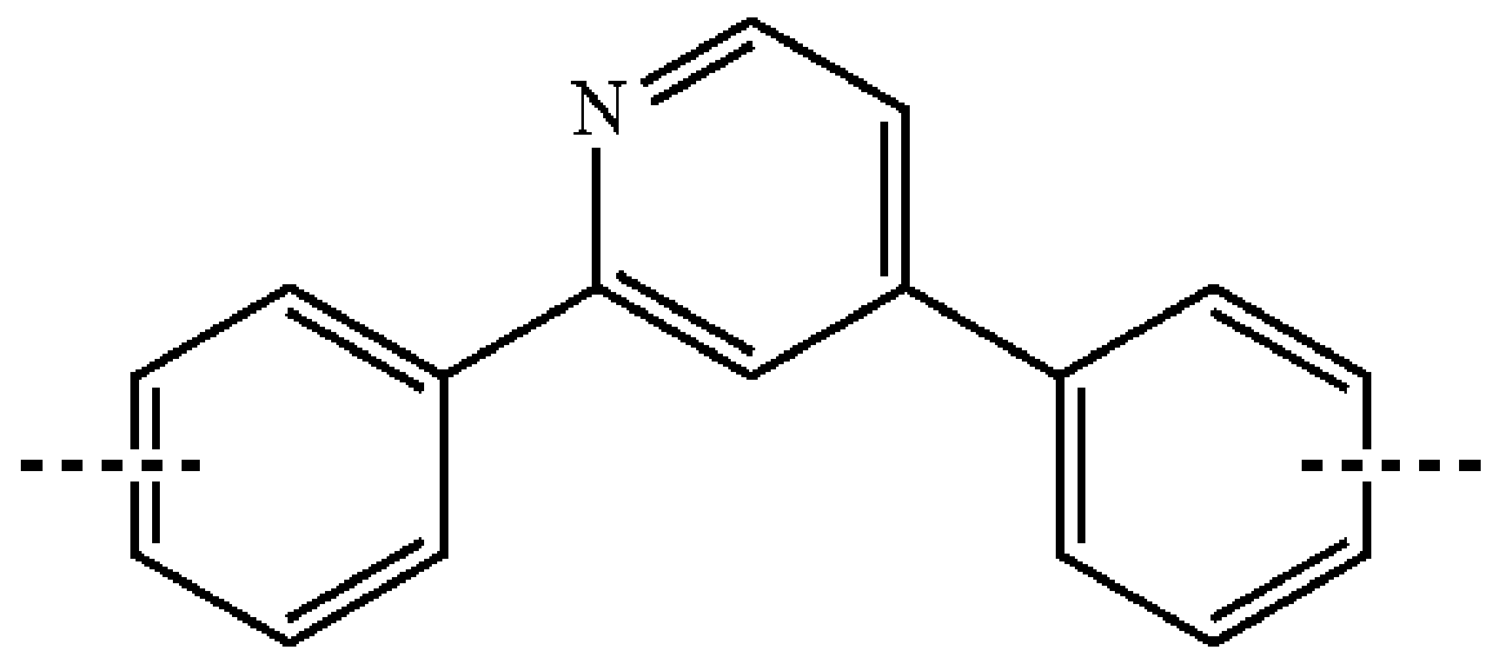
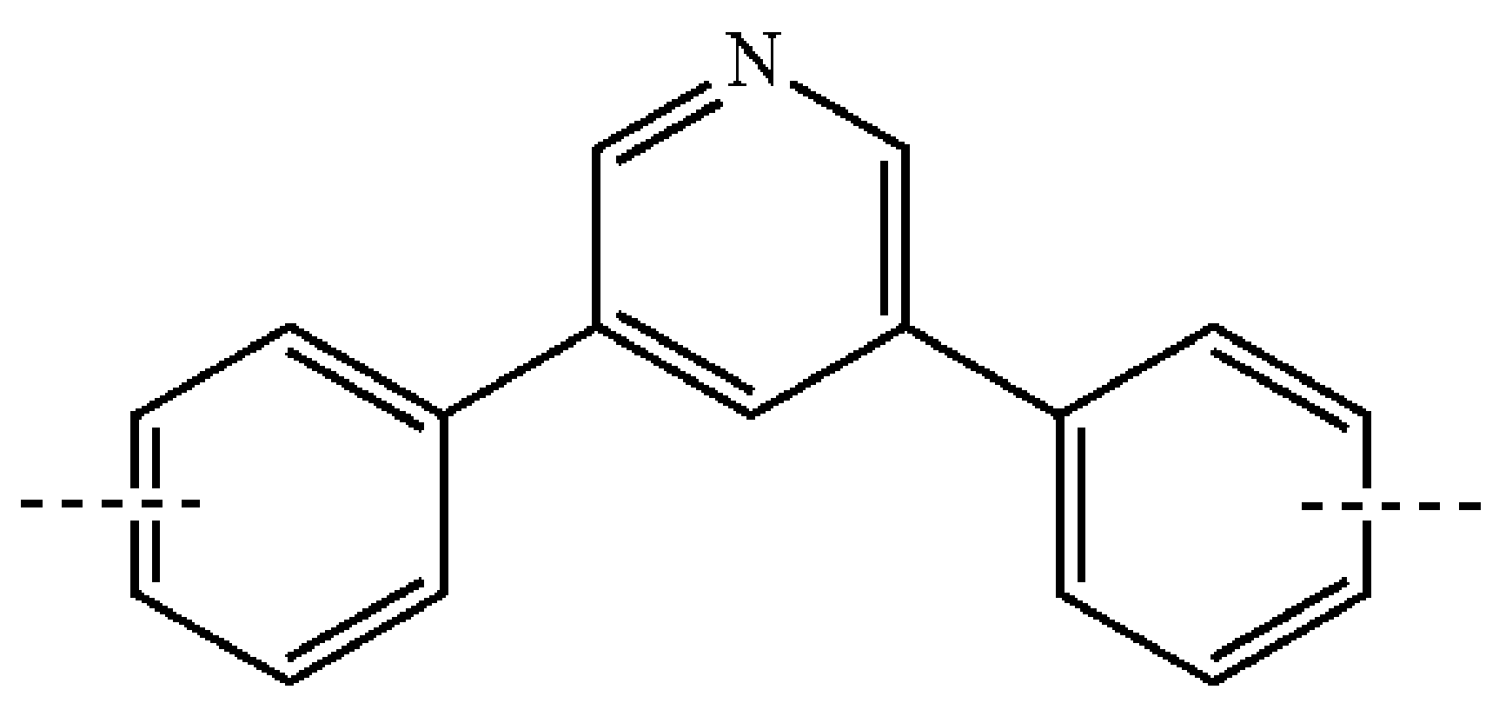
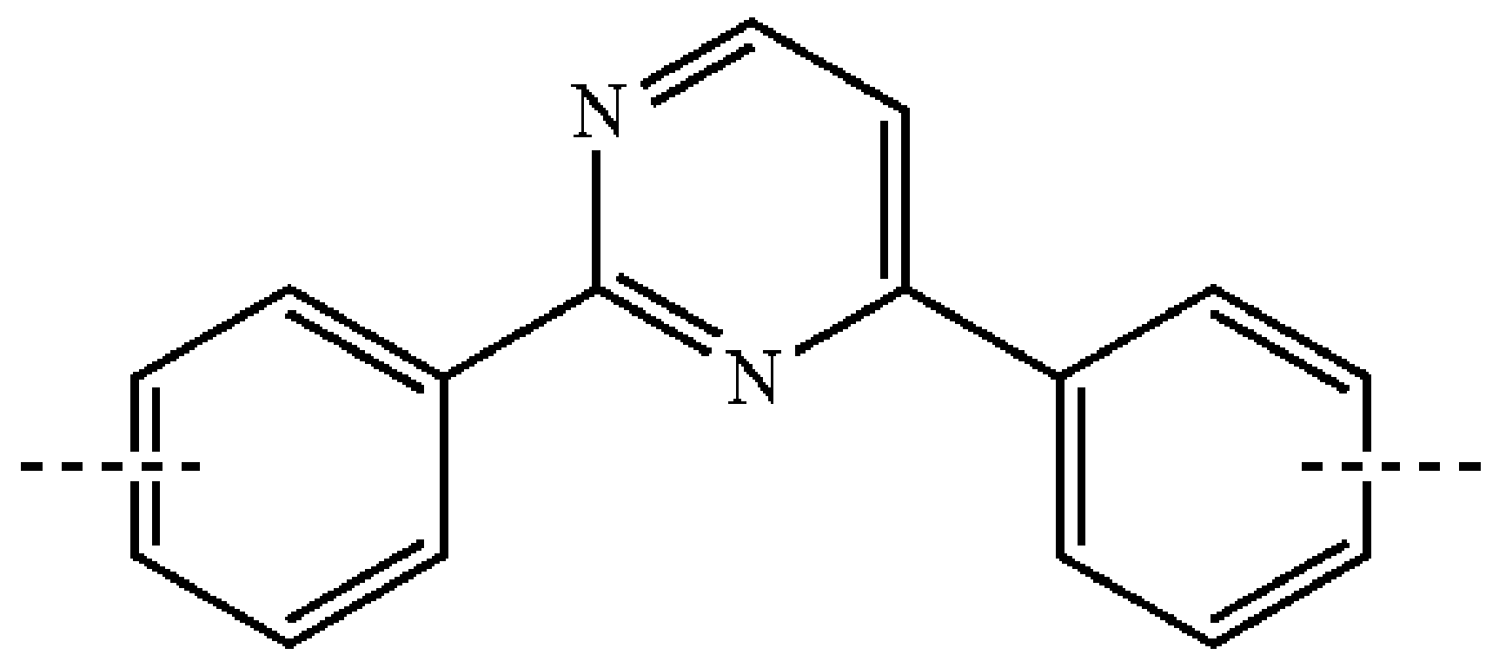
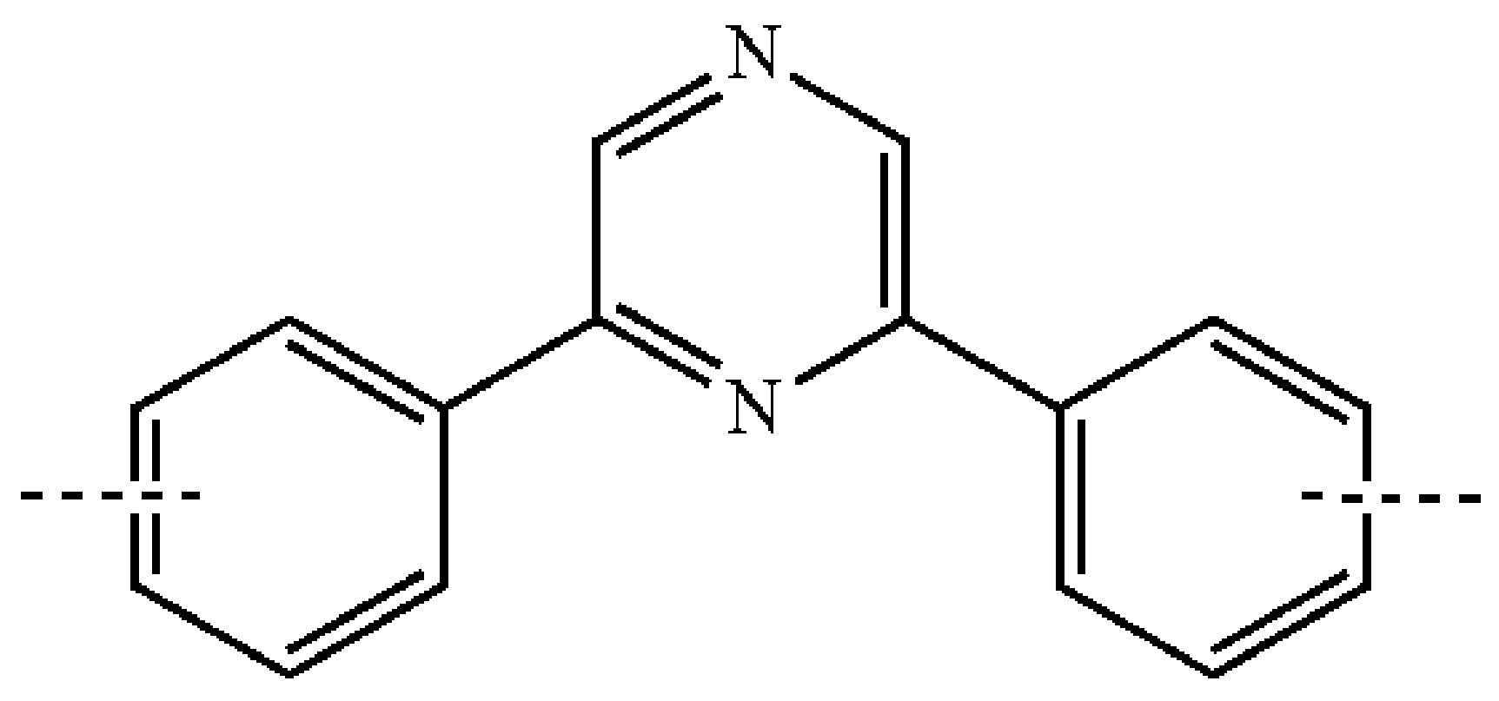
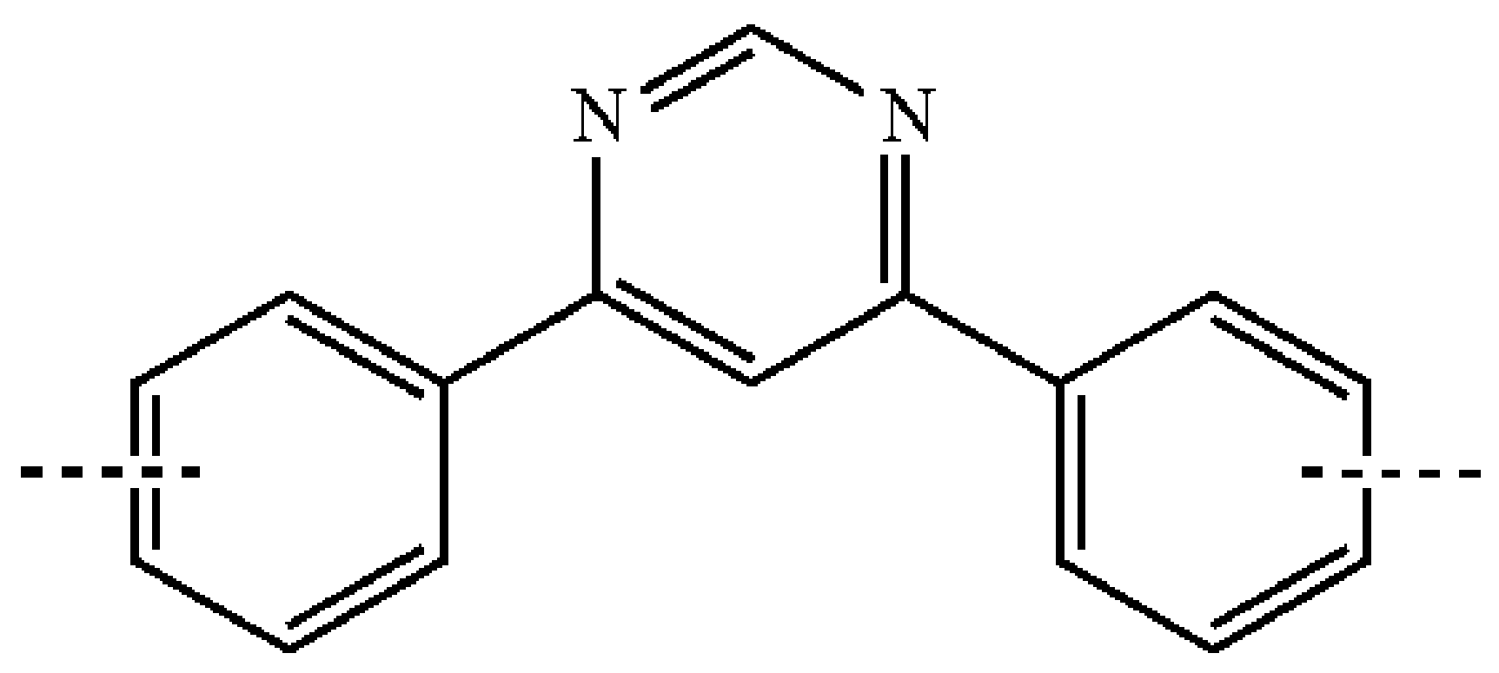
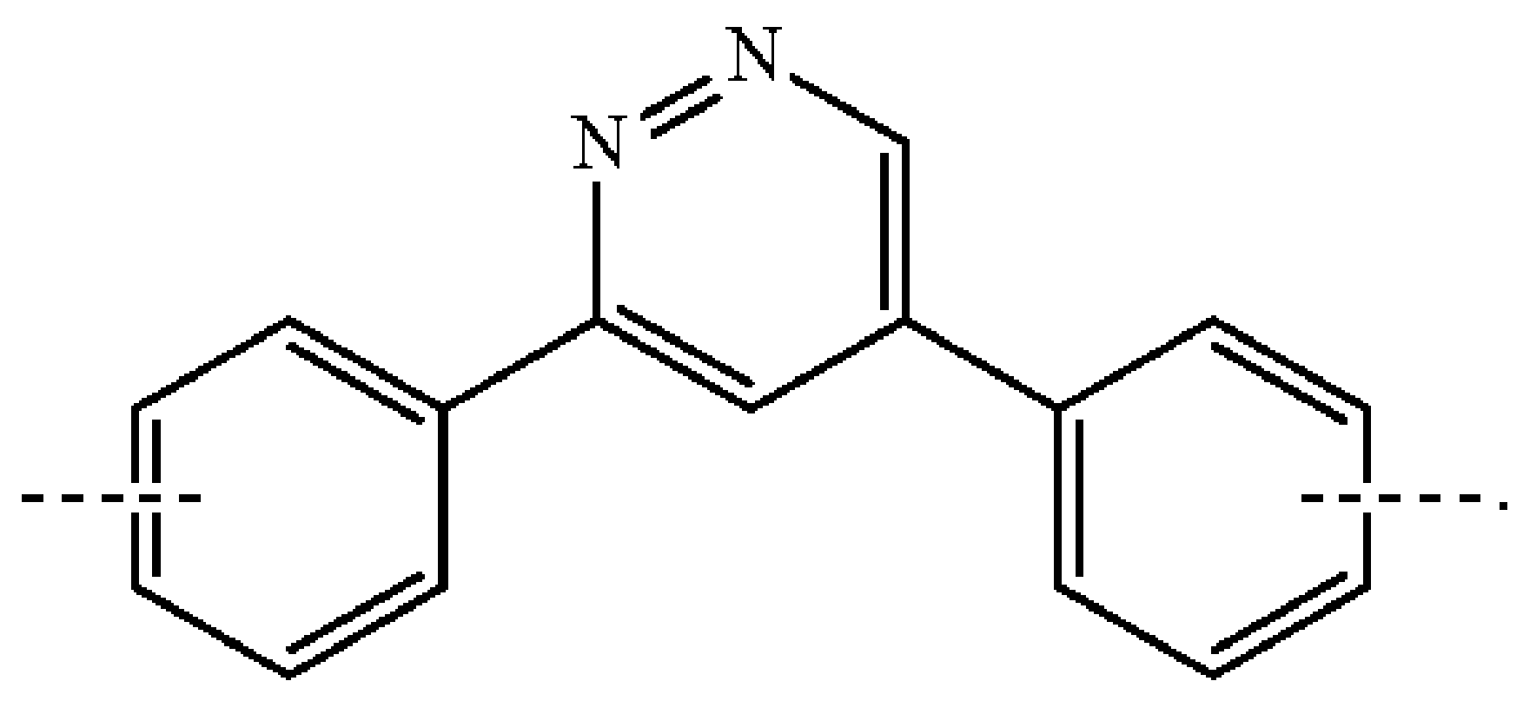
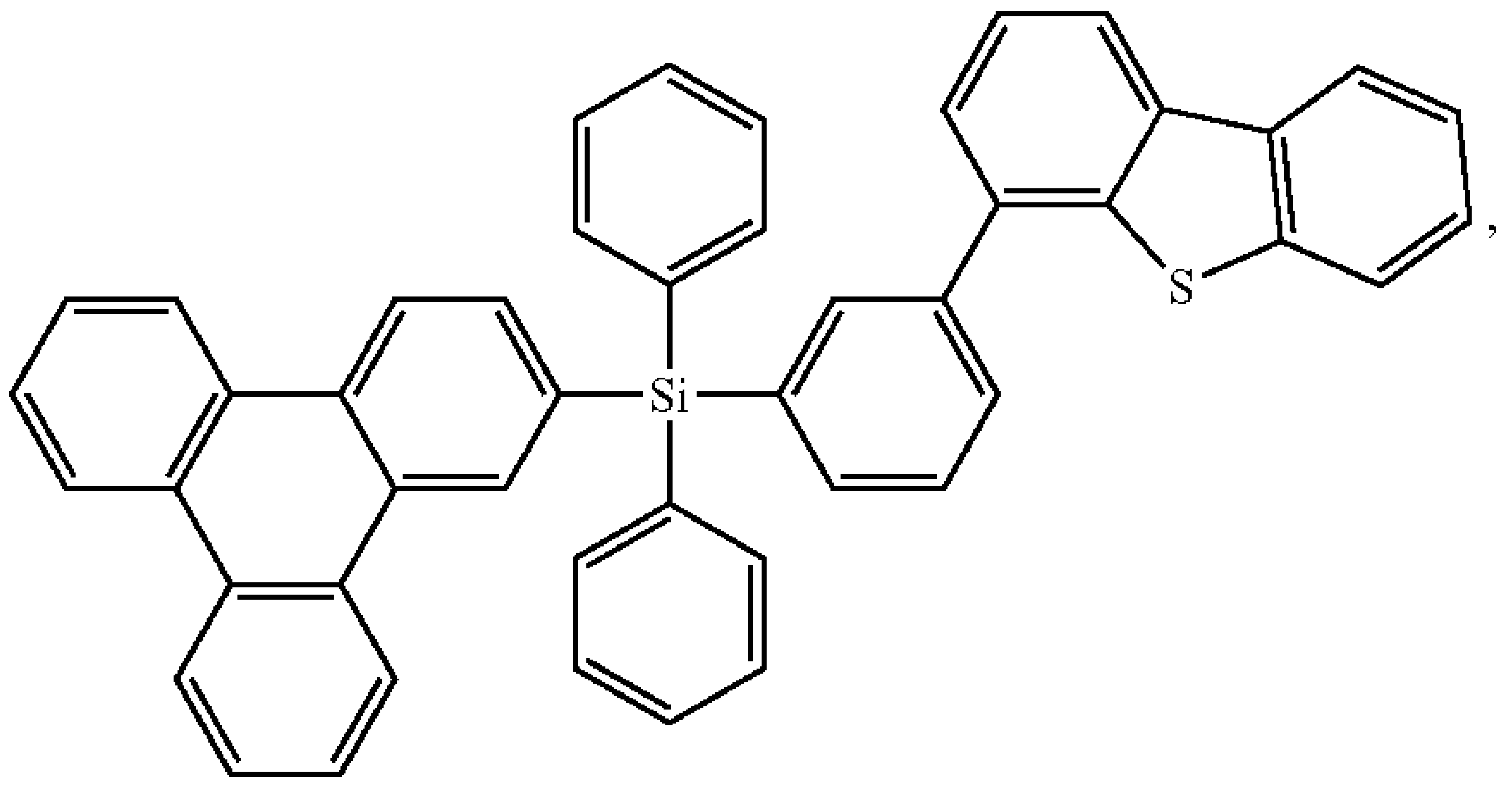








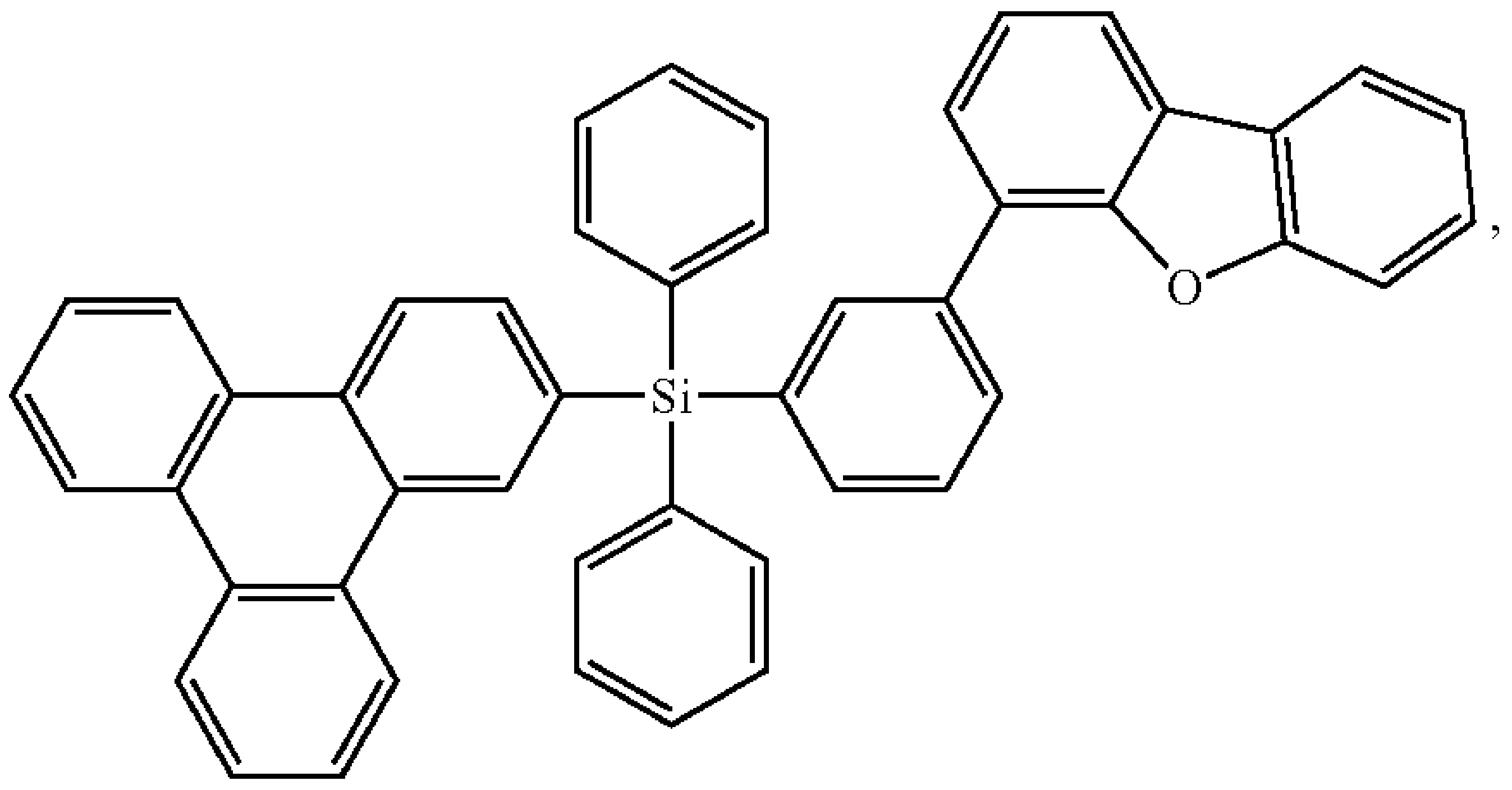
In one embodiment, A is tripheynylene. In another embodiment, A is pyrene. In one embodiment, Ar and Ar' are phenyl. In one embodiment, L is phenyl.

In one embodiment, the compound is selected from the group consisting of:

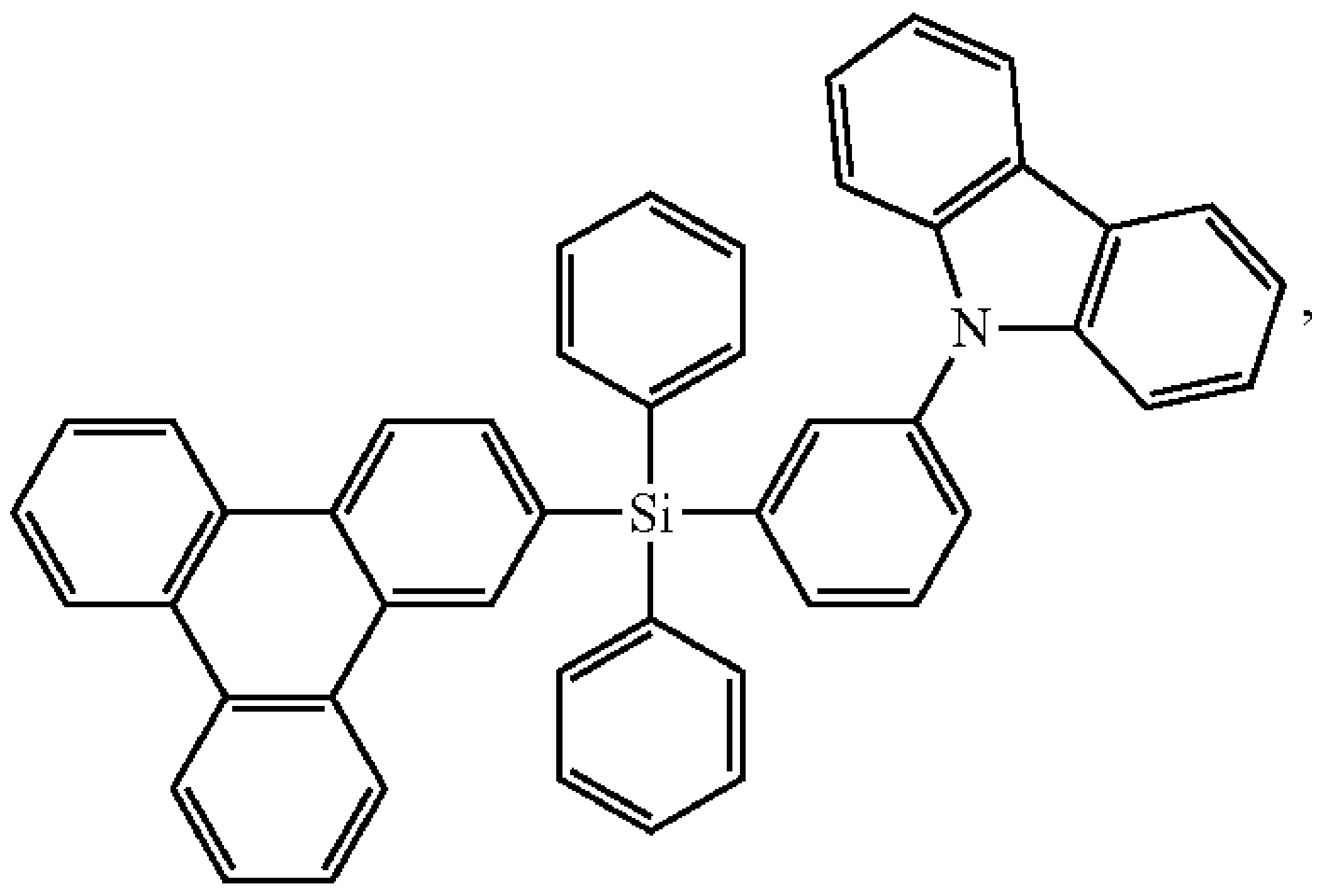
Compound 1



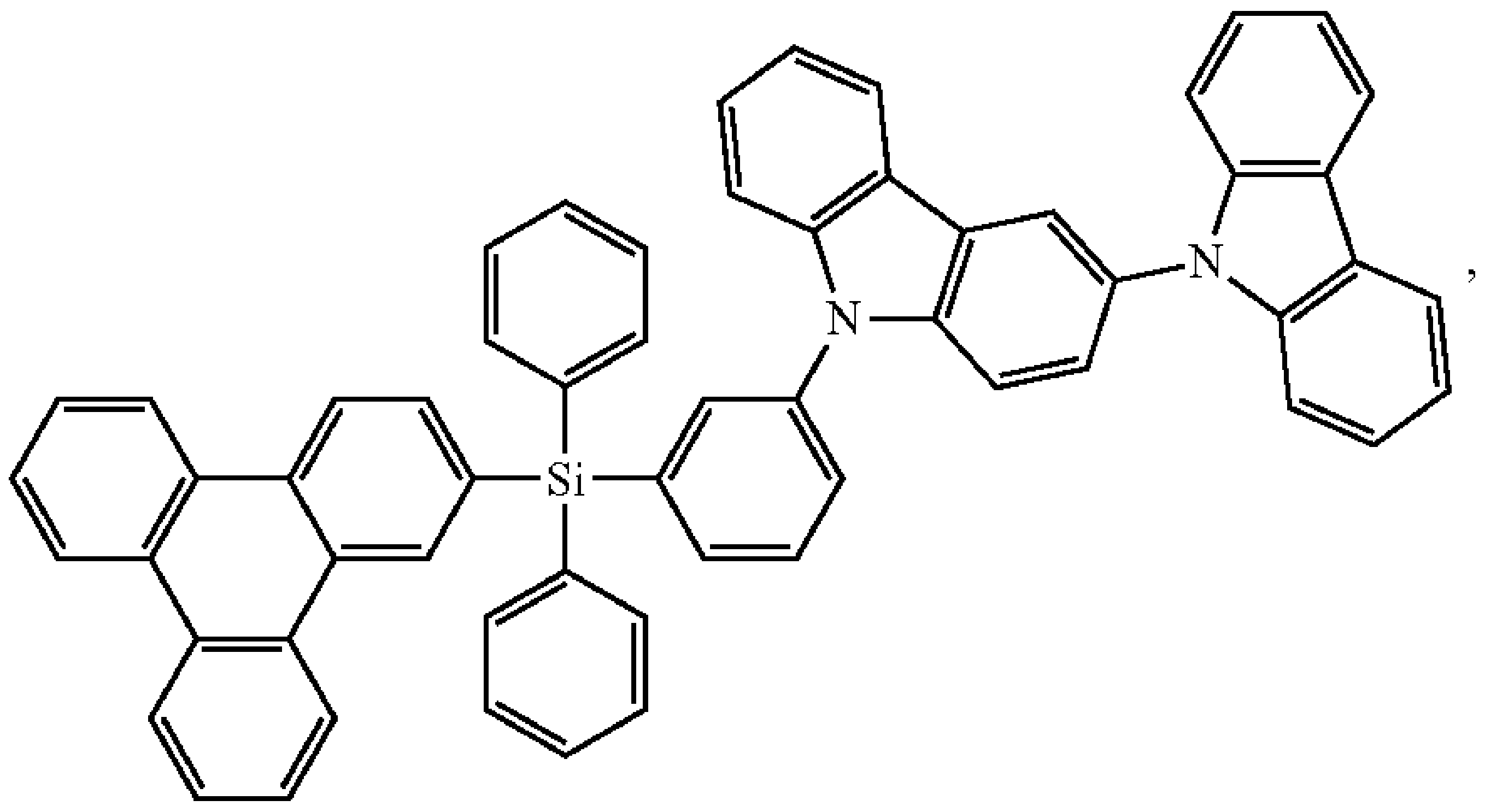
Compound 2



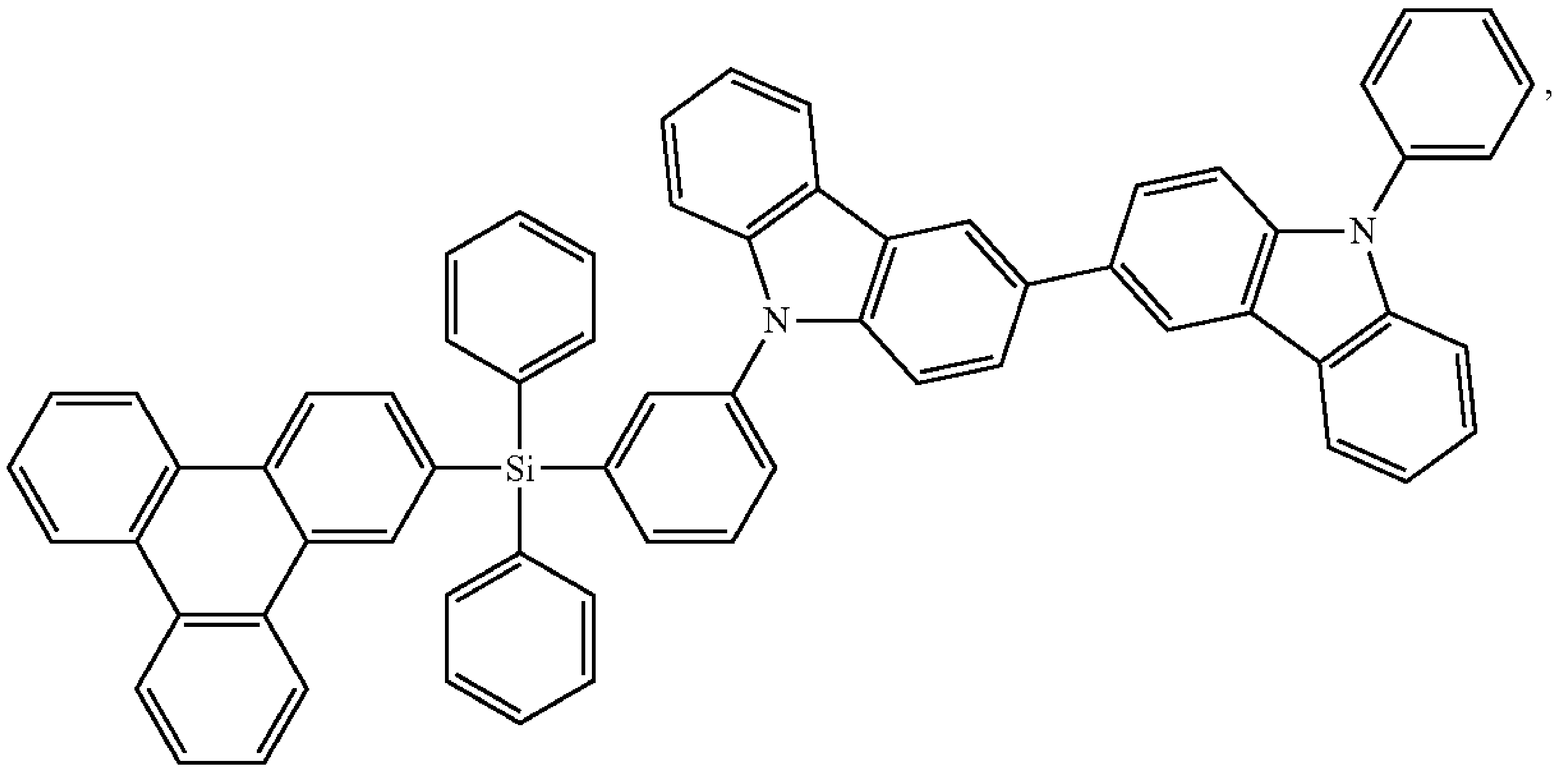
Compound 3



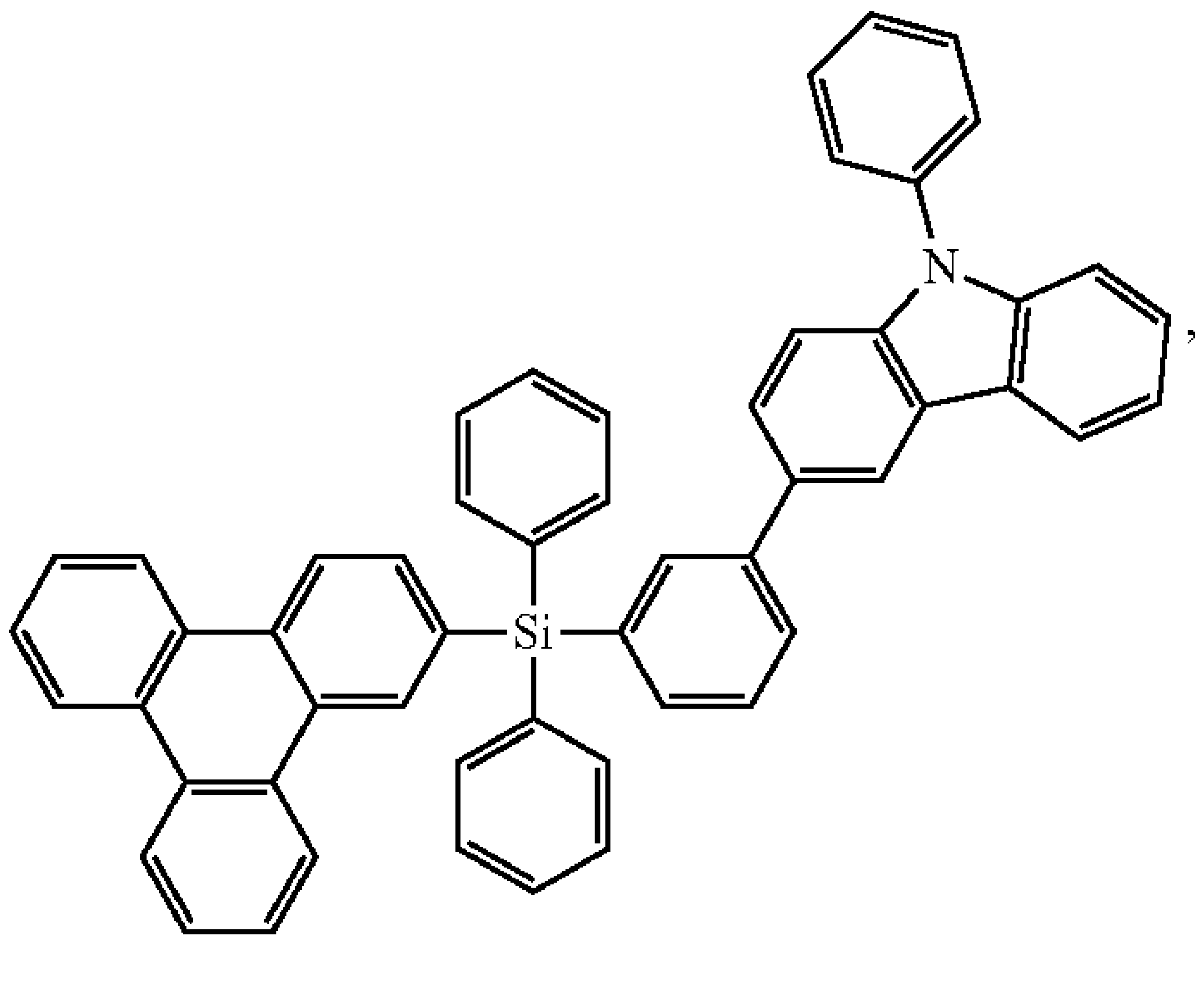
Compound 4



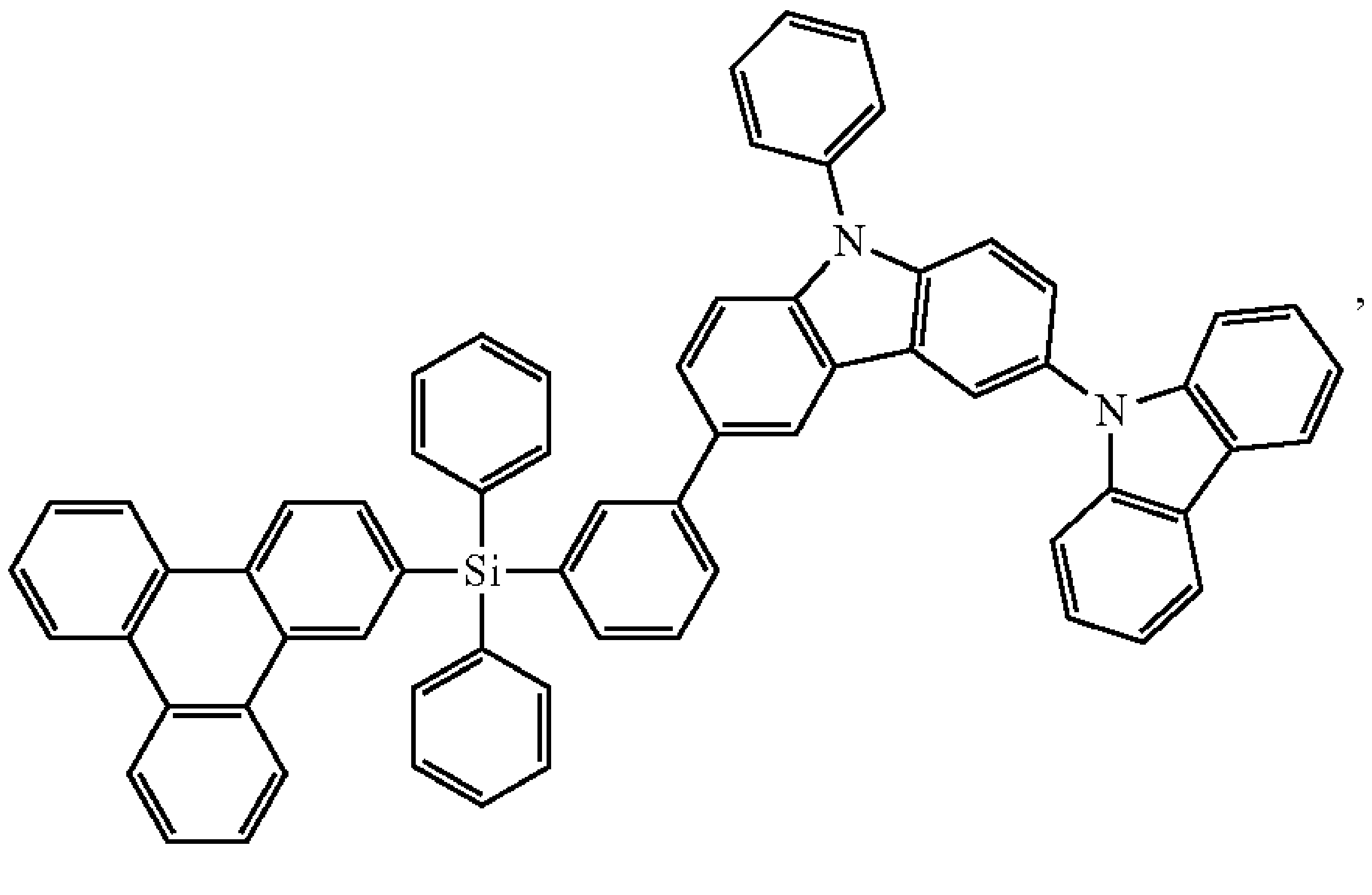
Compound 5



Compound 6



Compound 7



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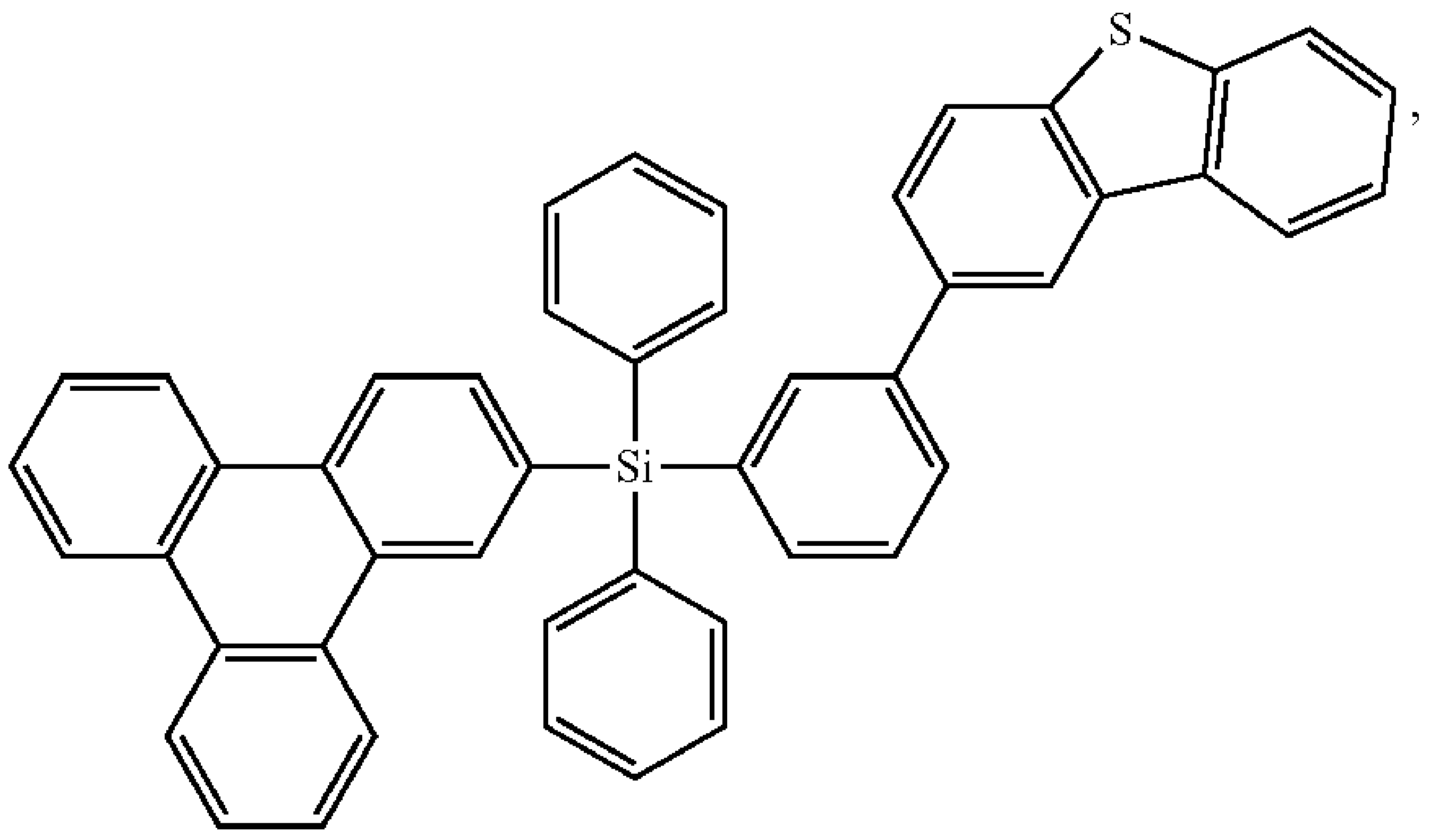
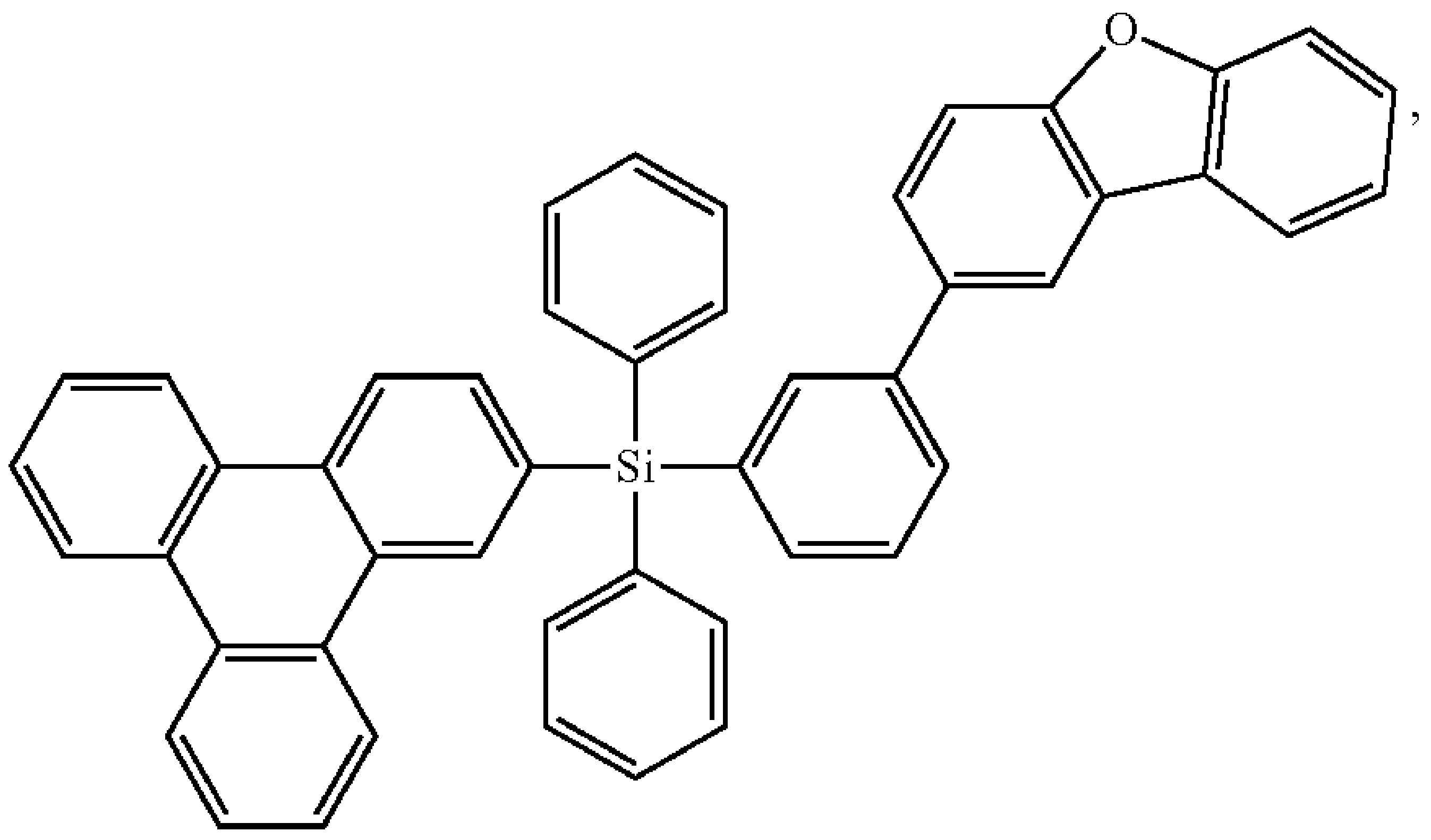
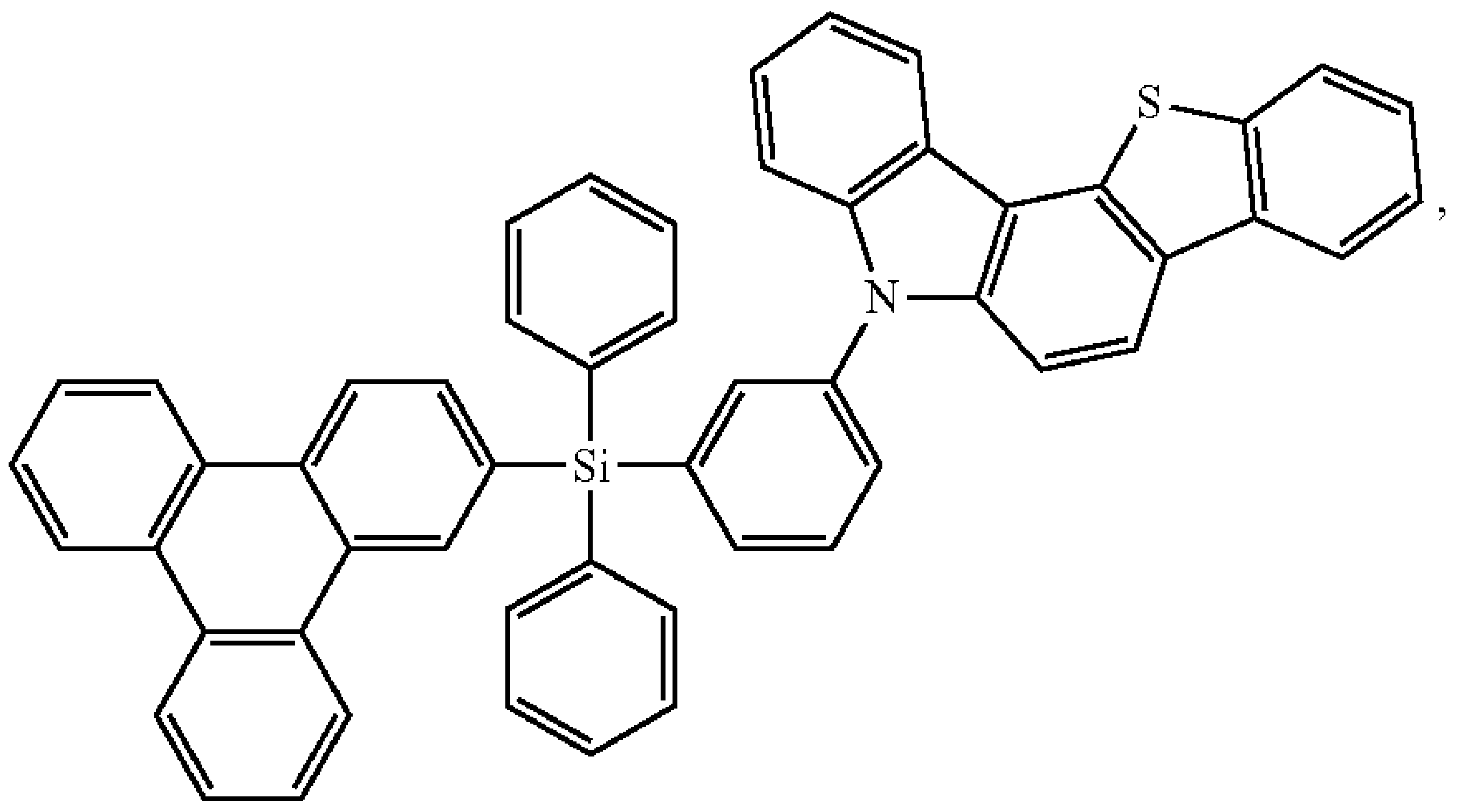
Compound 8



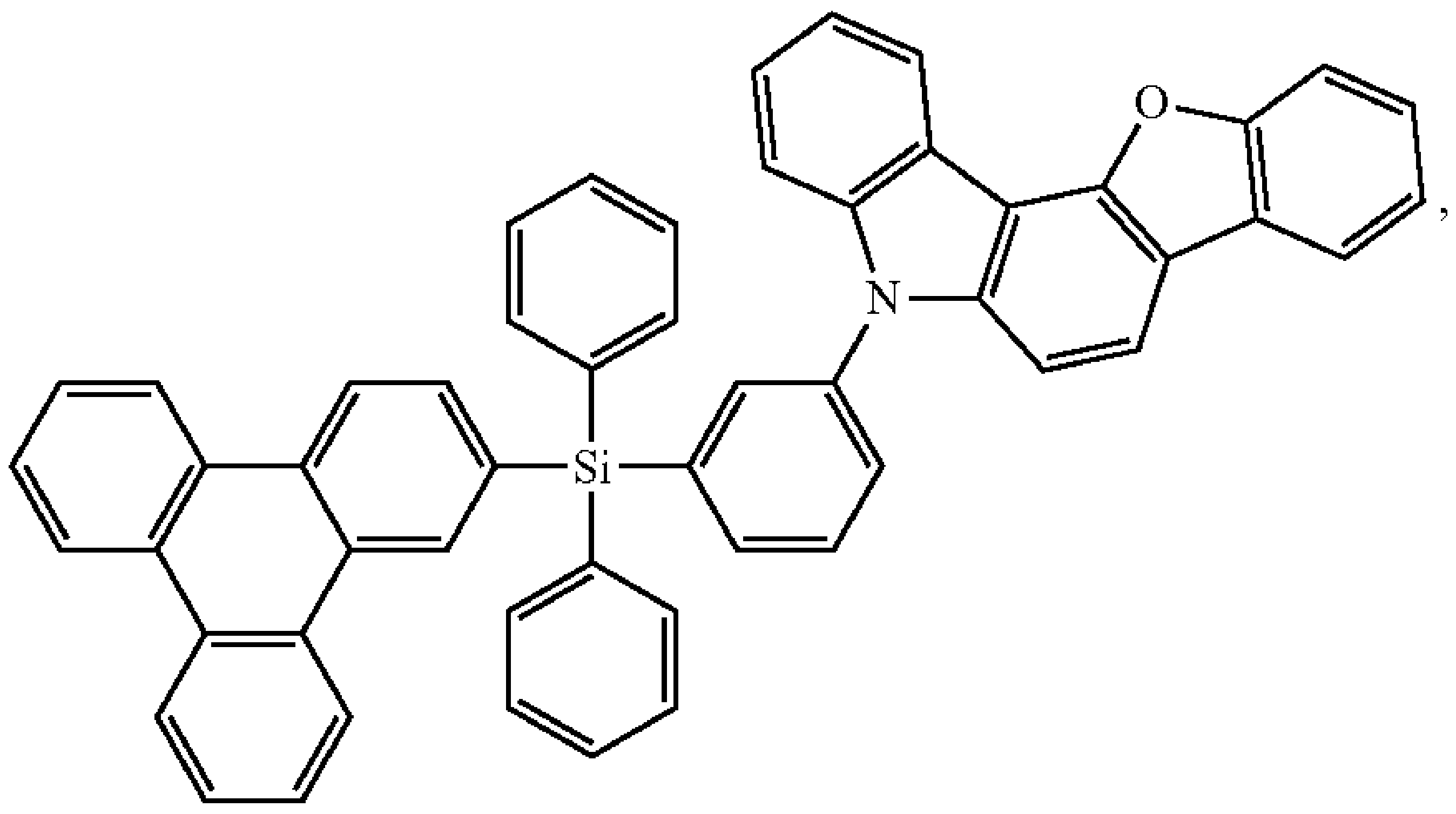
Compound 9



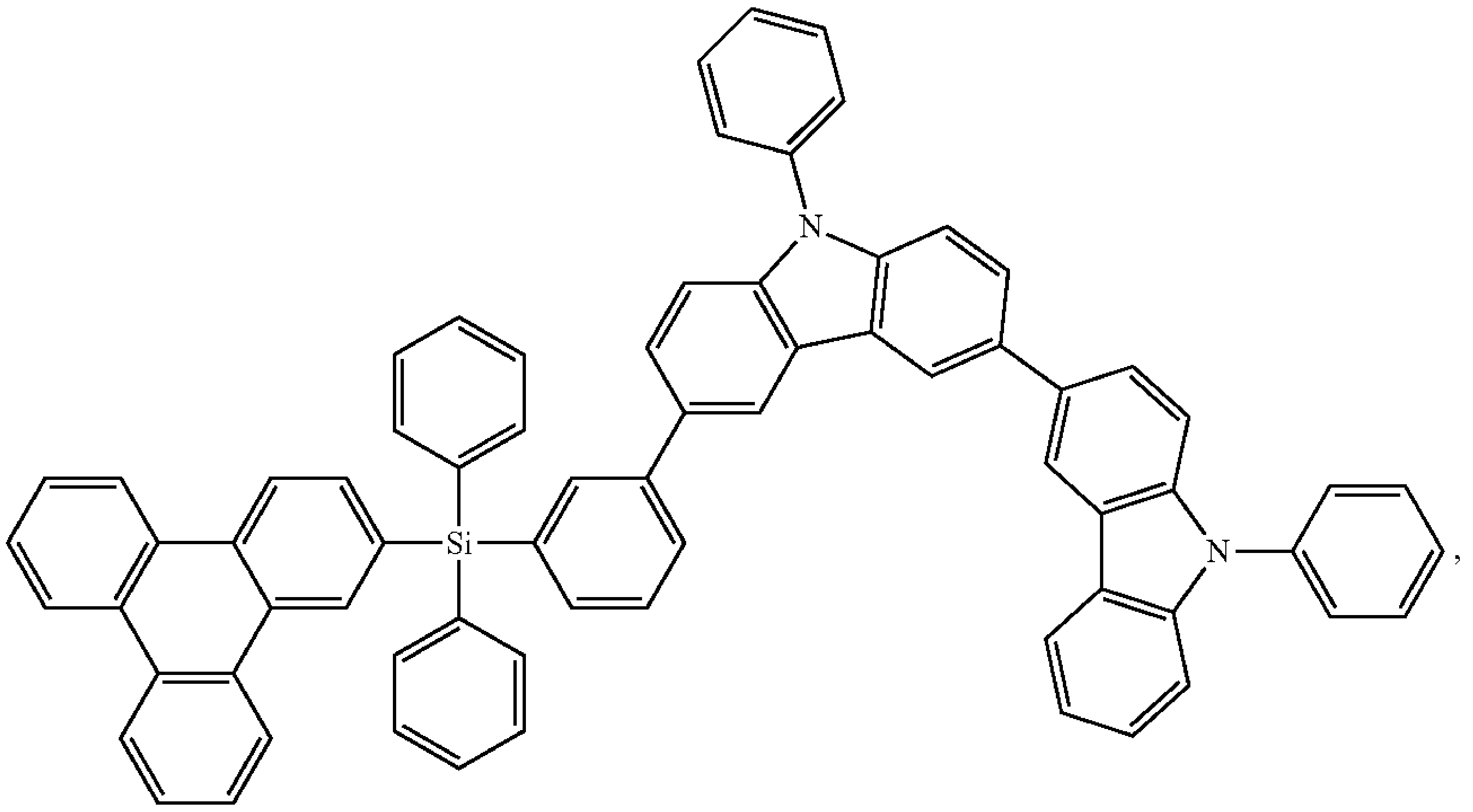
Compound 10



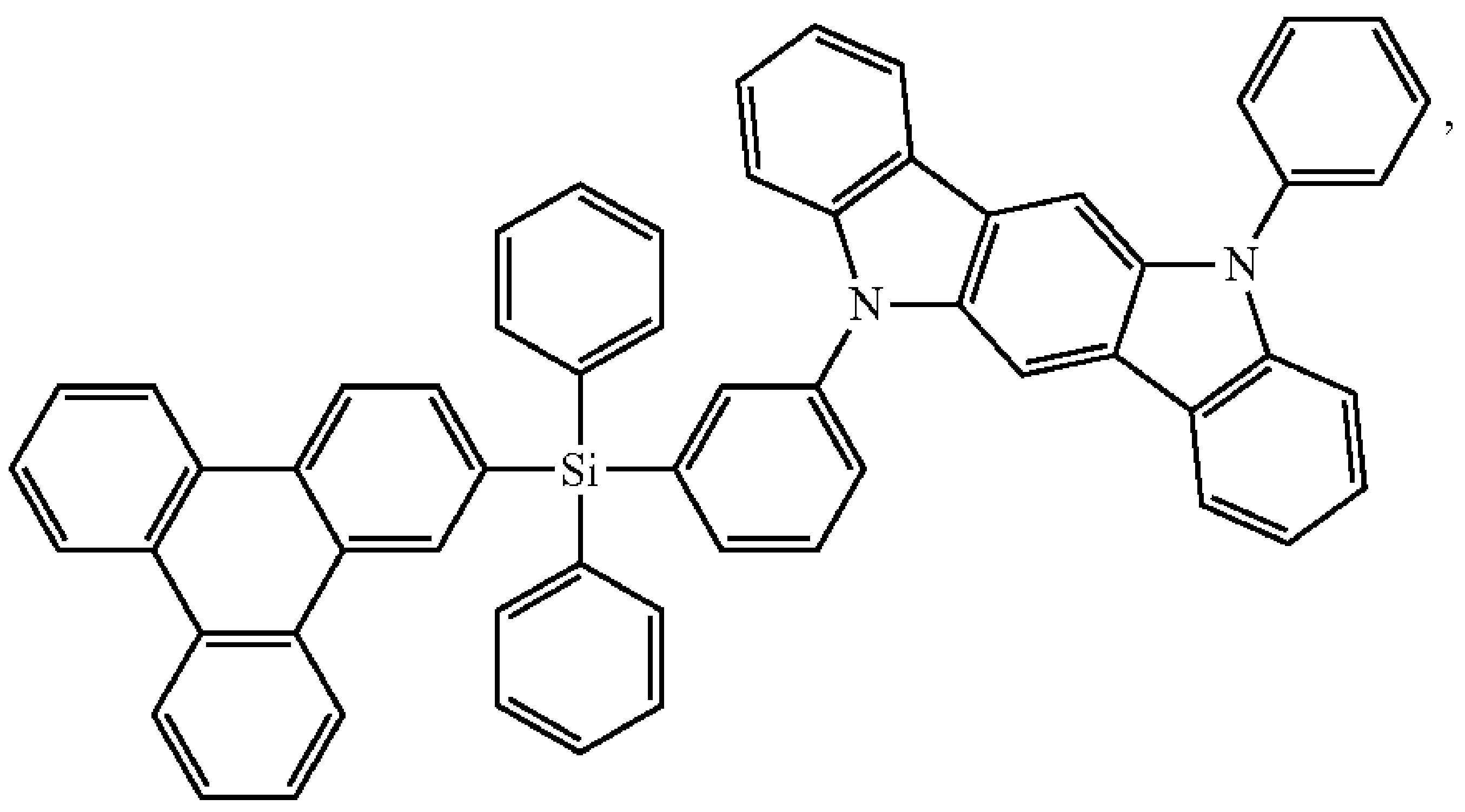
Compound 11



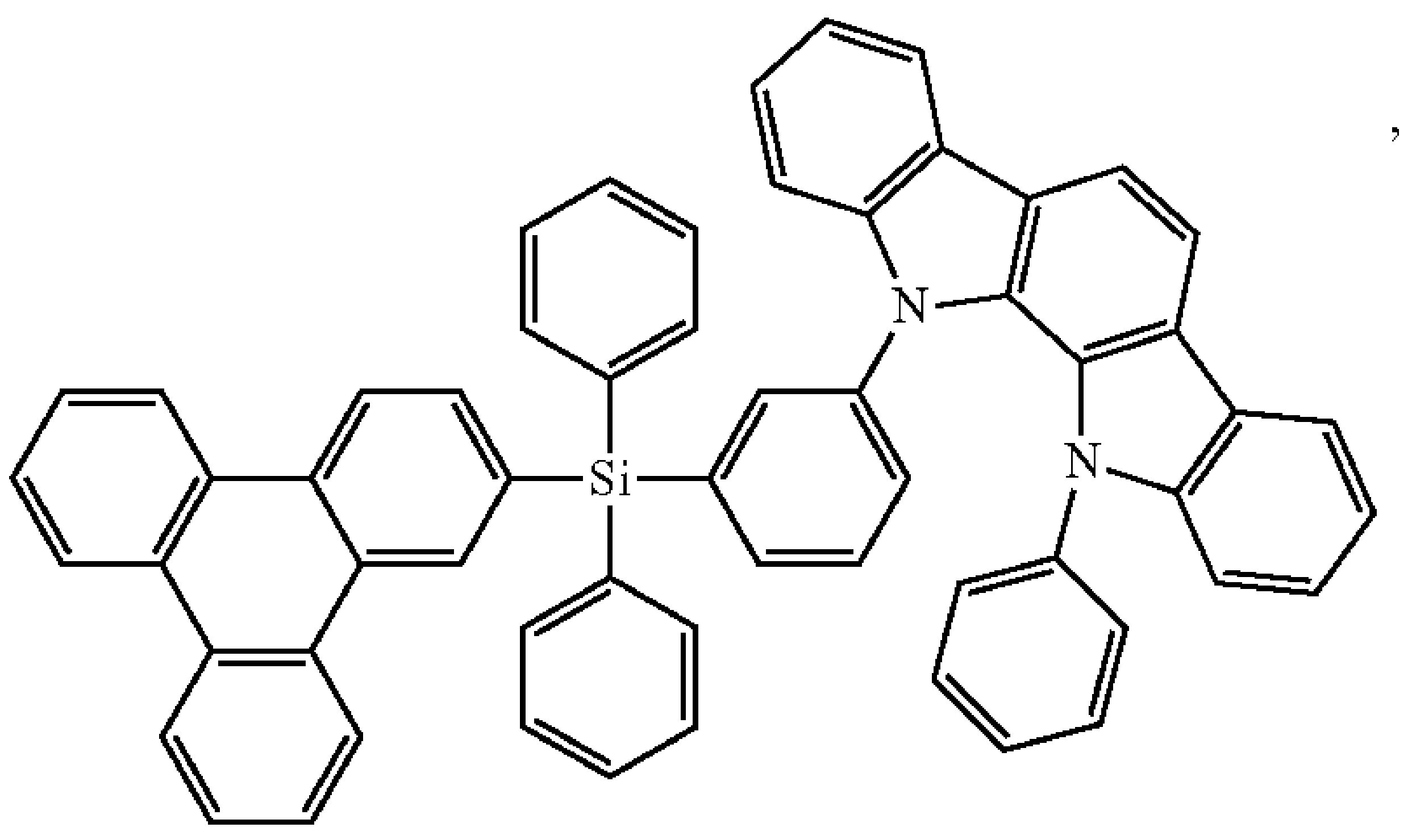
Compound 12



Compound 13



Compound 14



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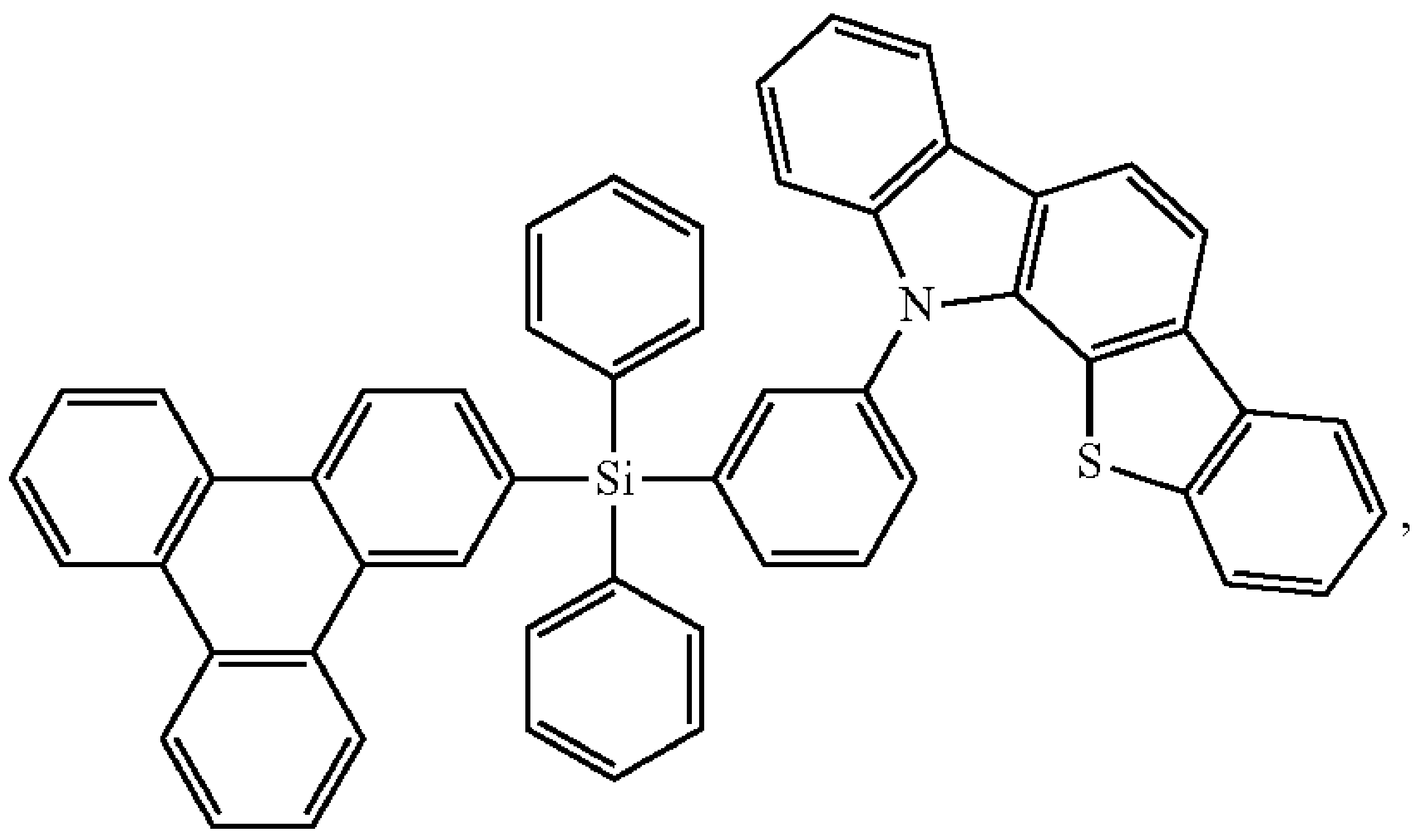
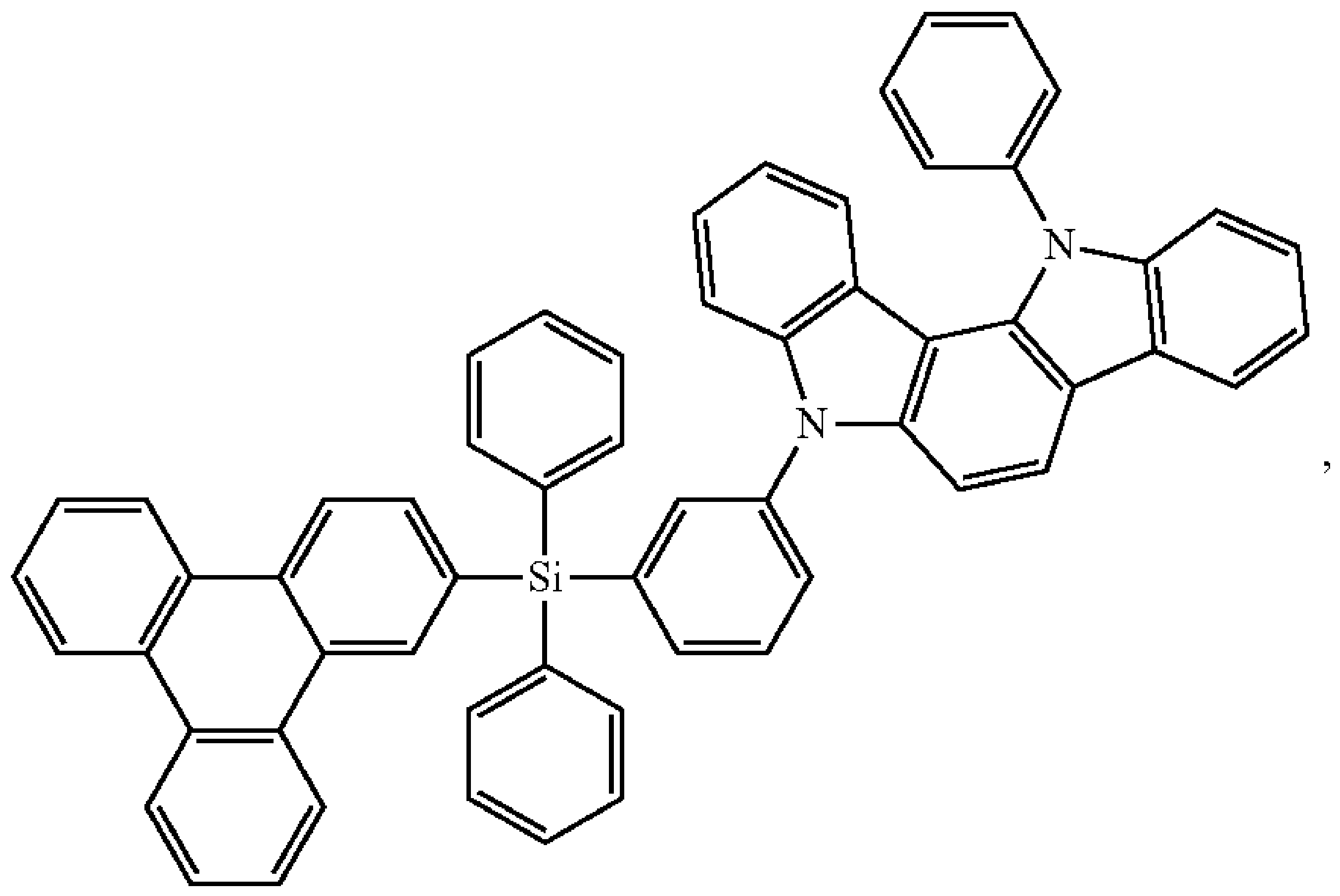
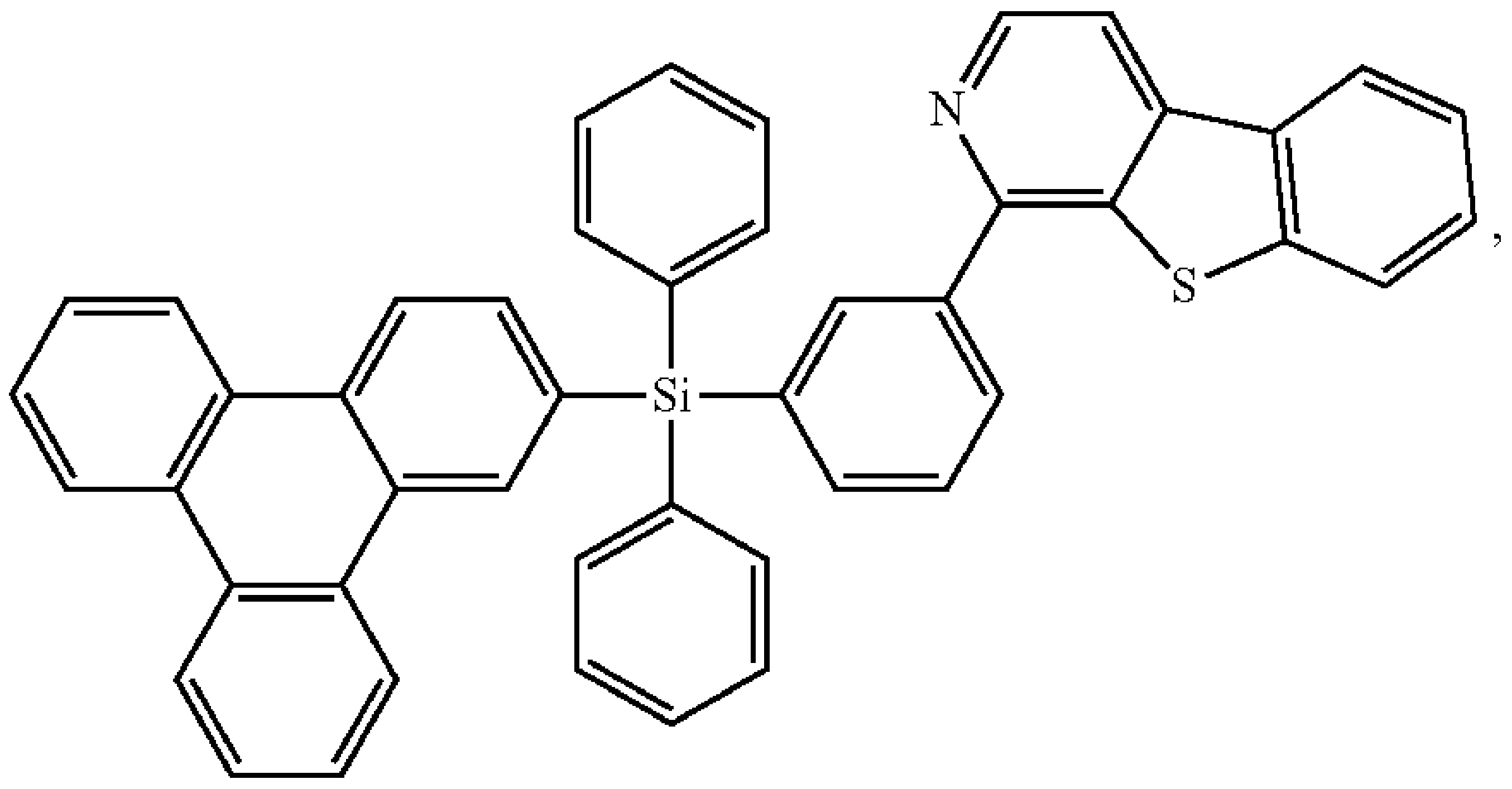
Compound 15



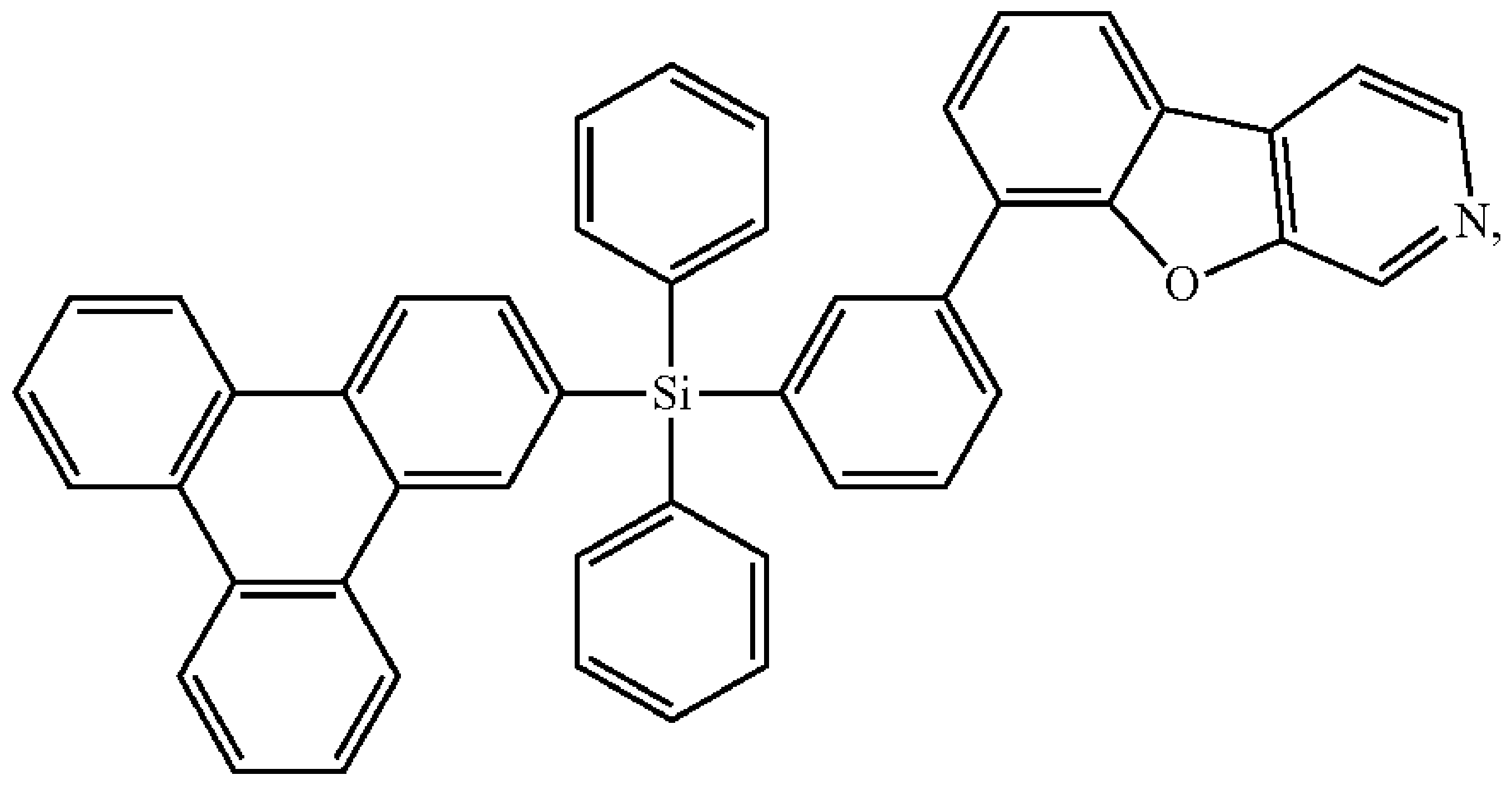
Compound 16



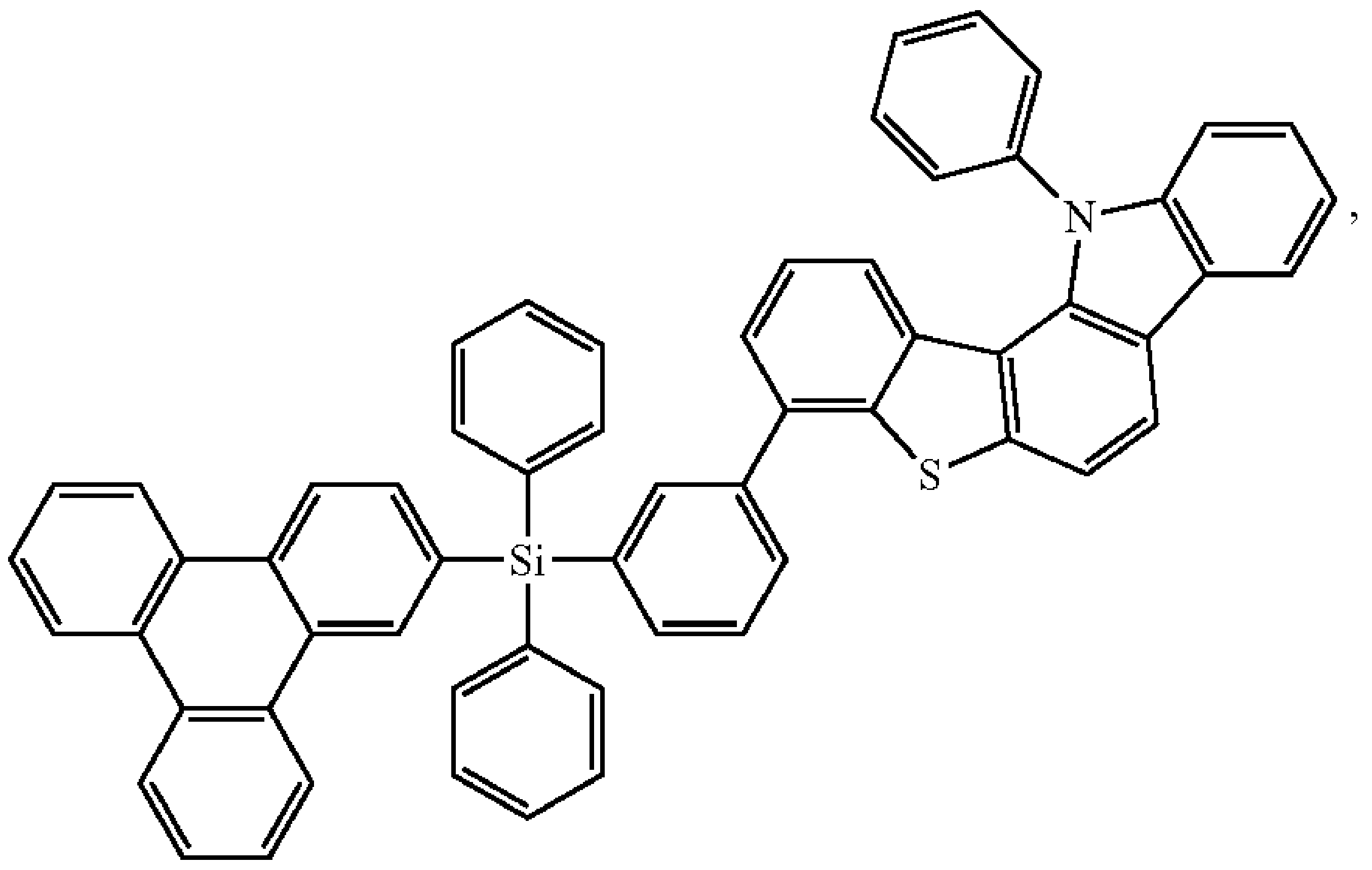
Compound 17



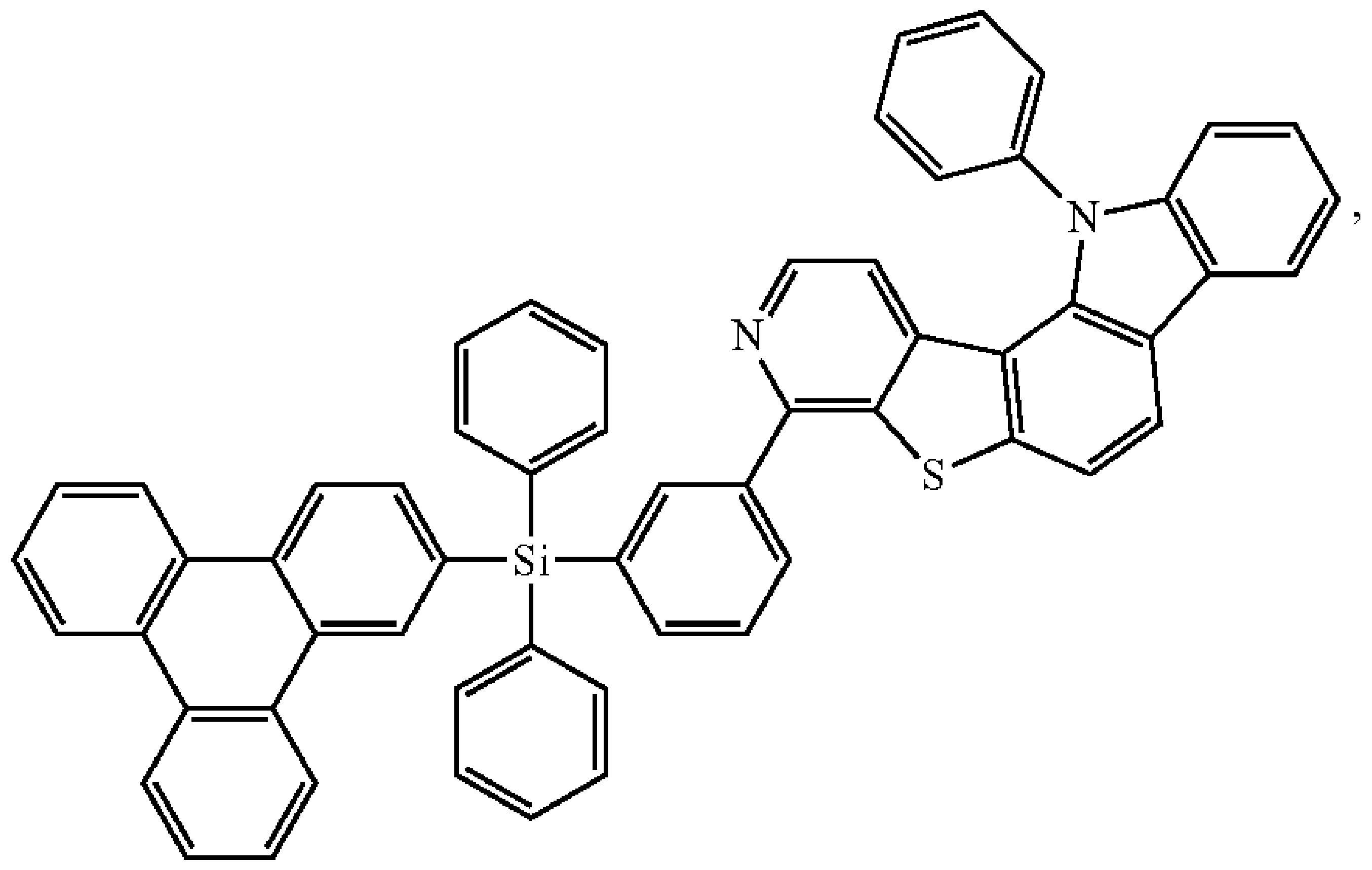
Compound 18



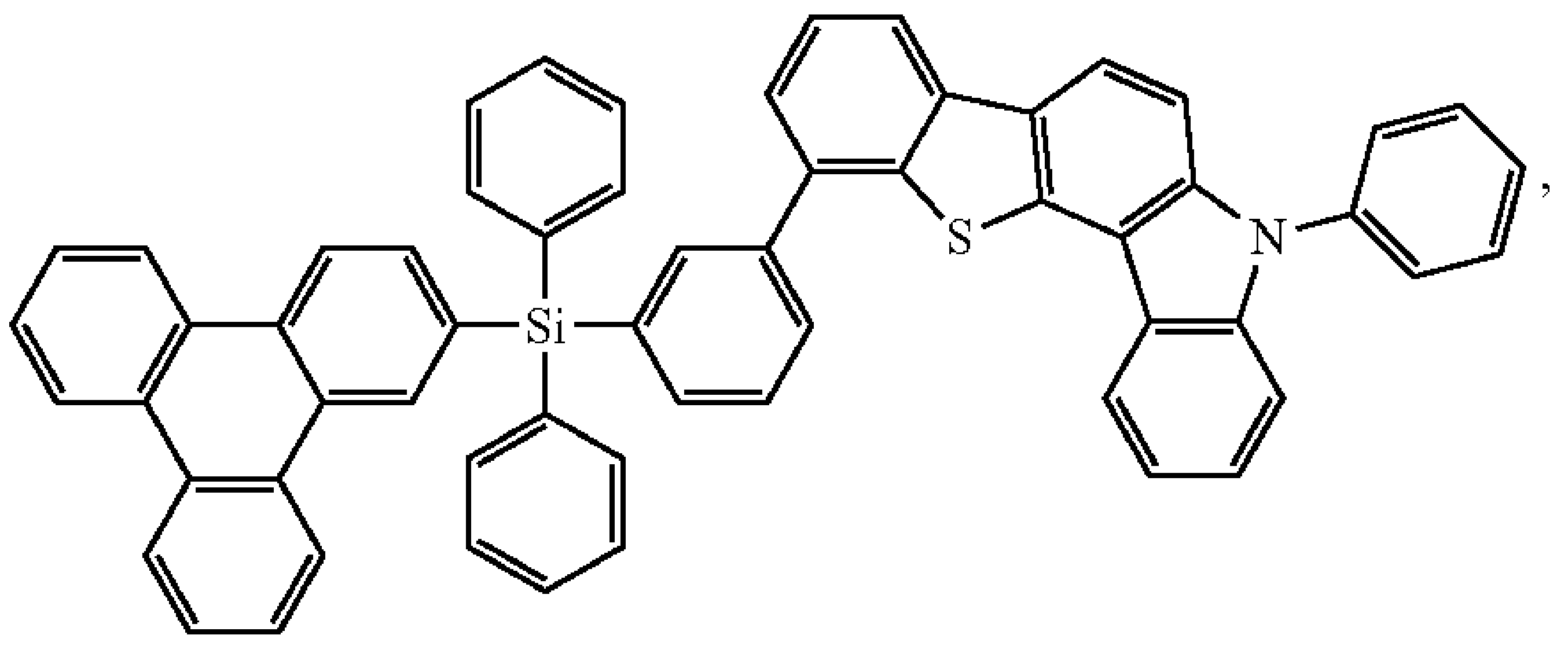
Compound 19



Compound 20



Compound 21



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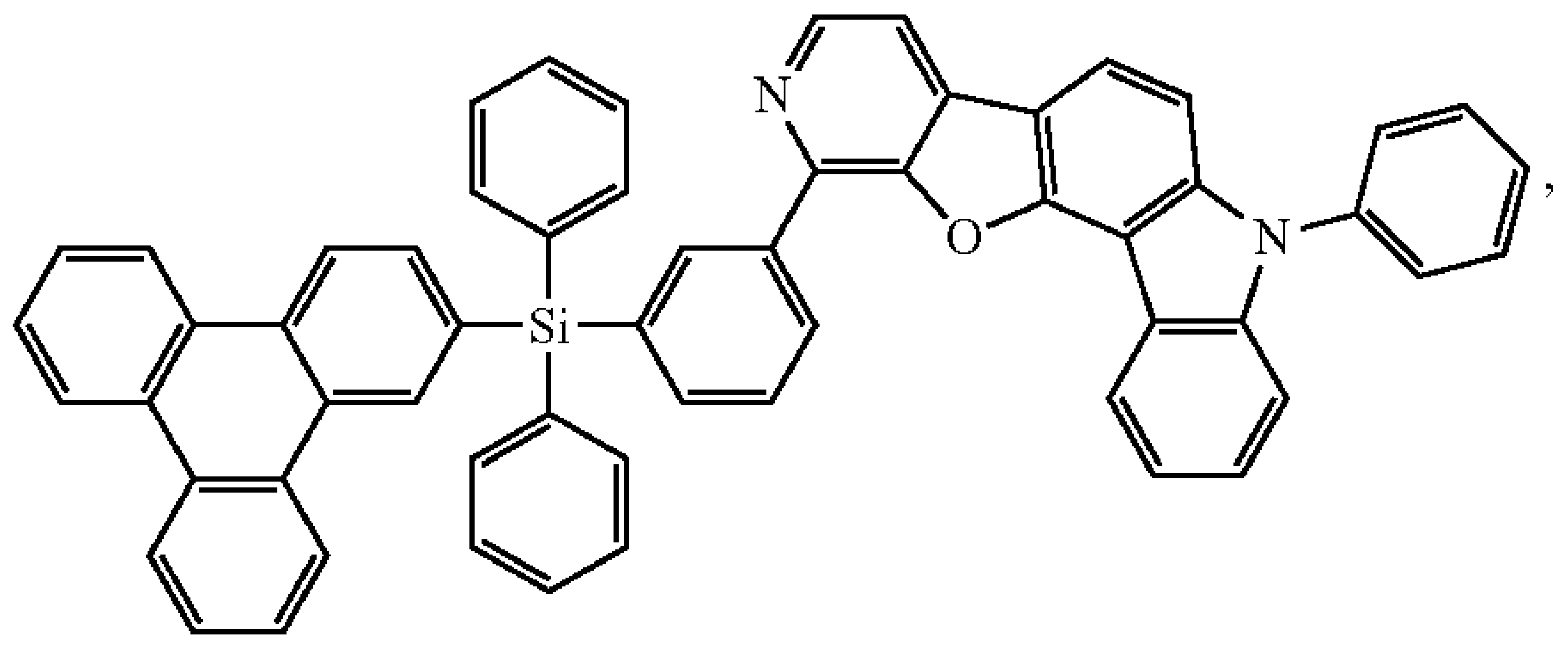

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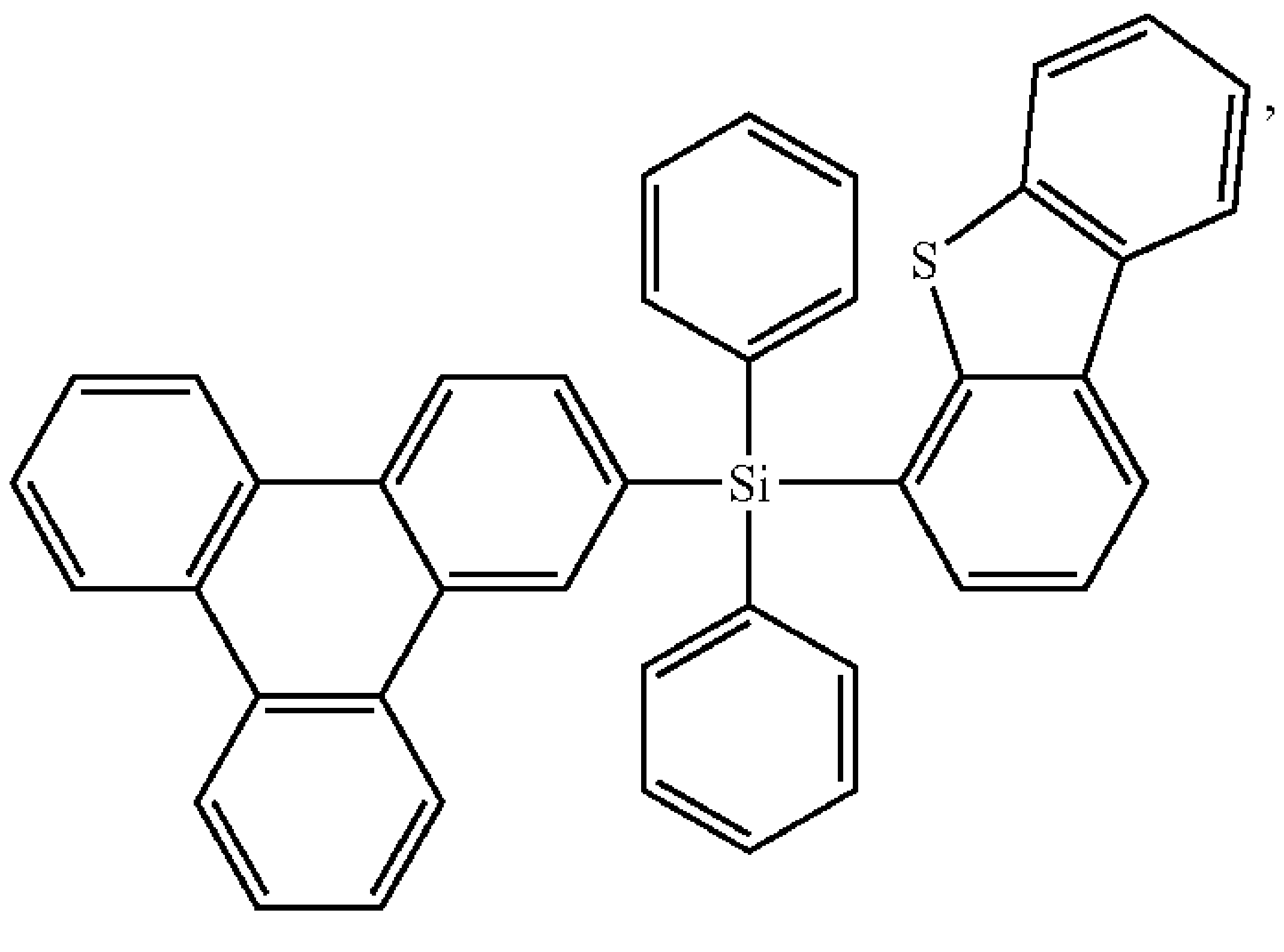

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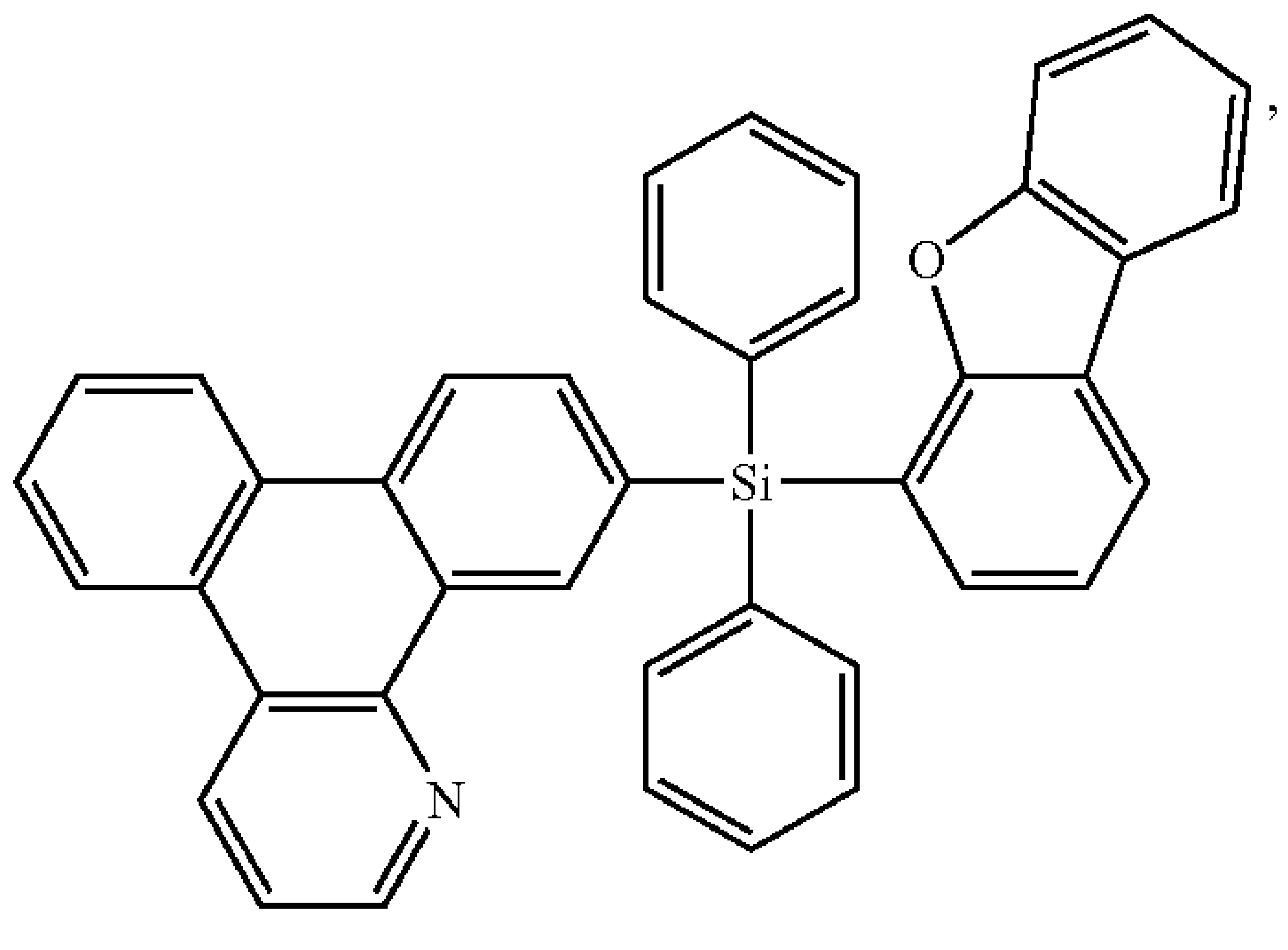

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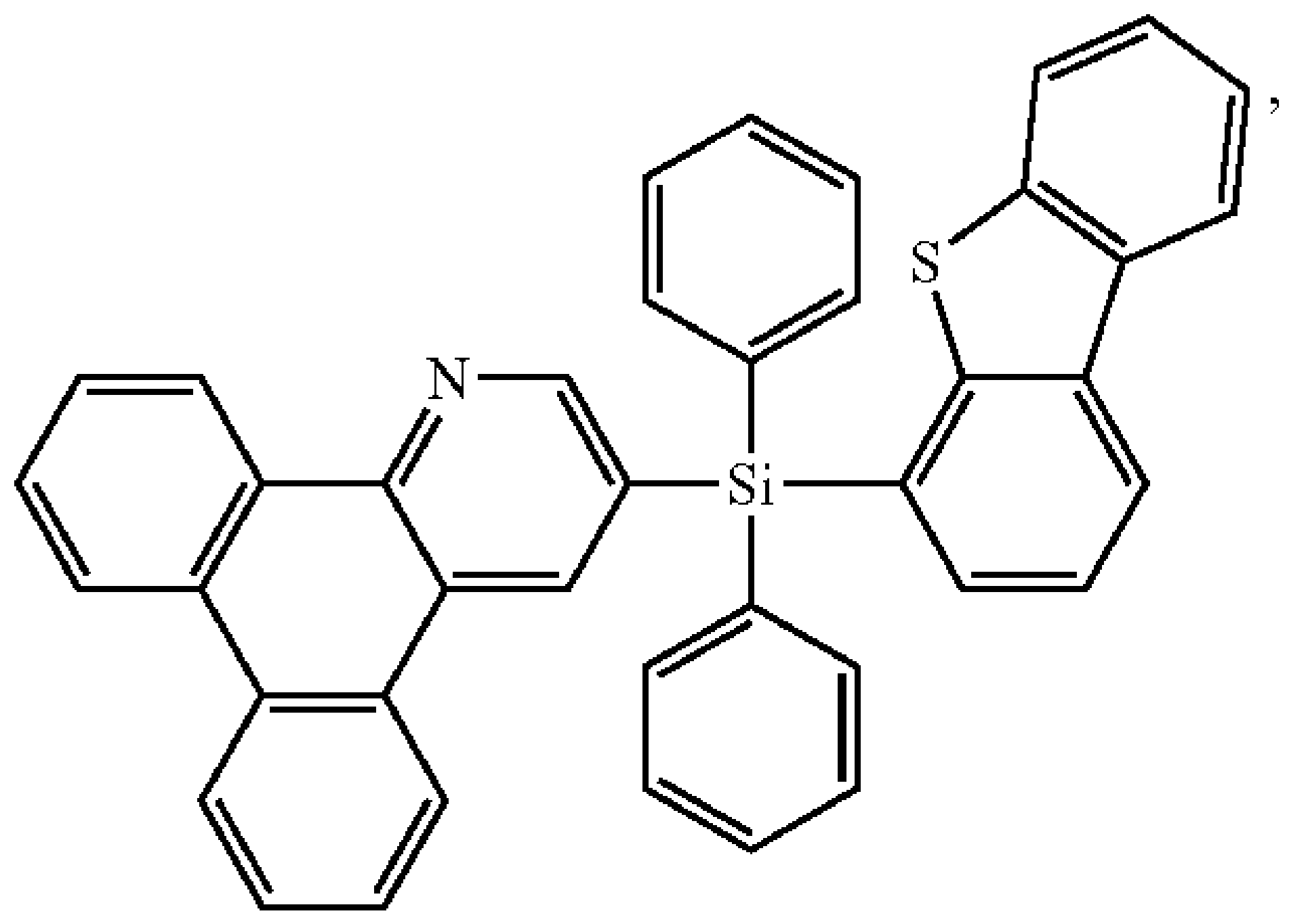
Compound 25



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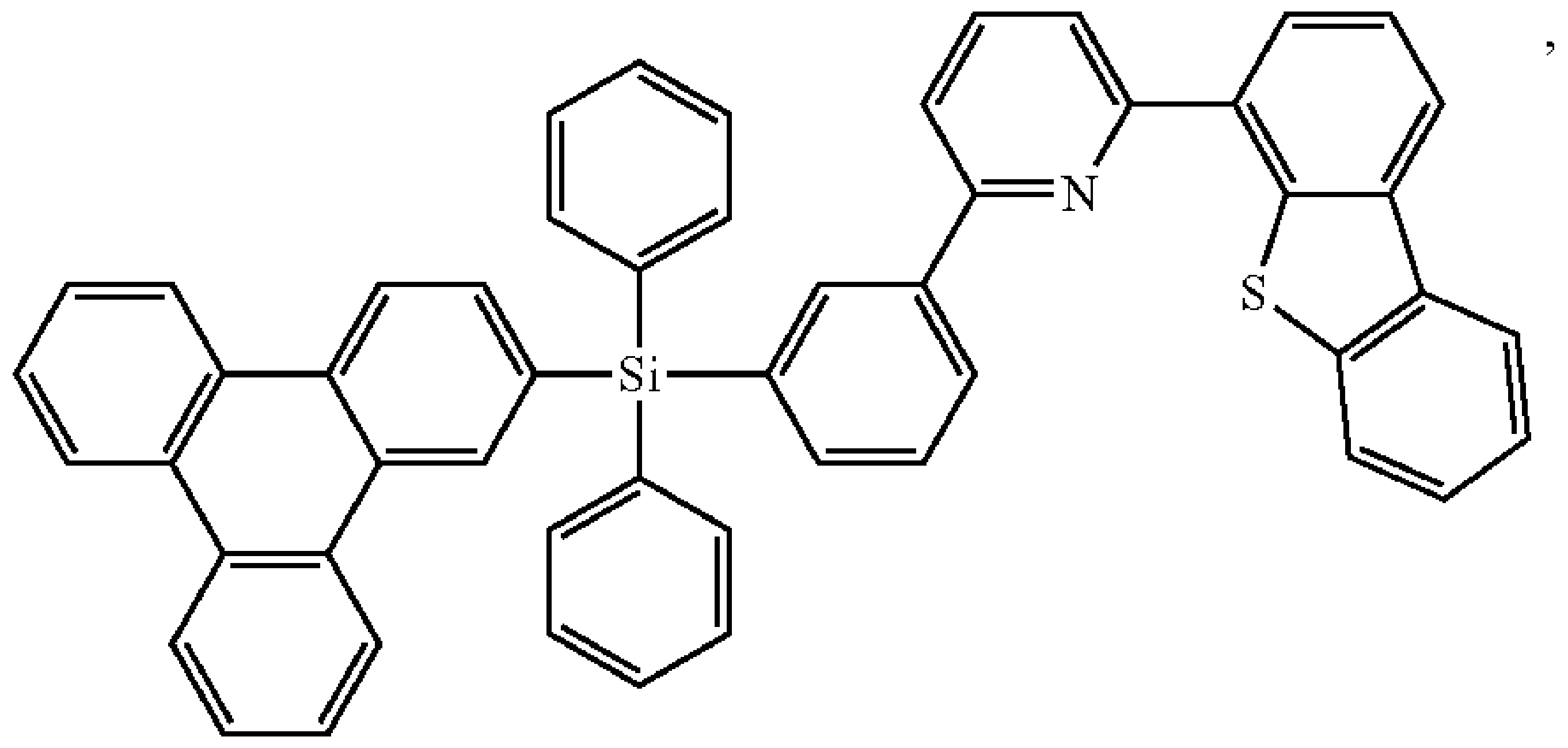

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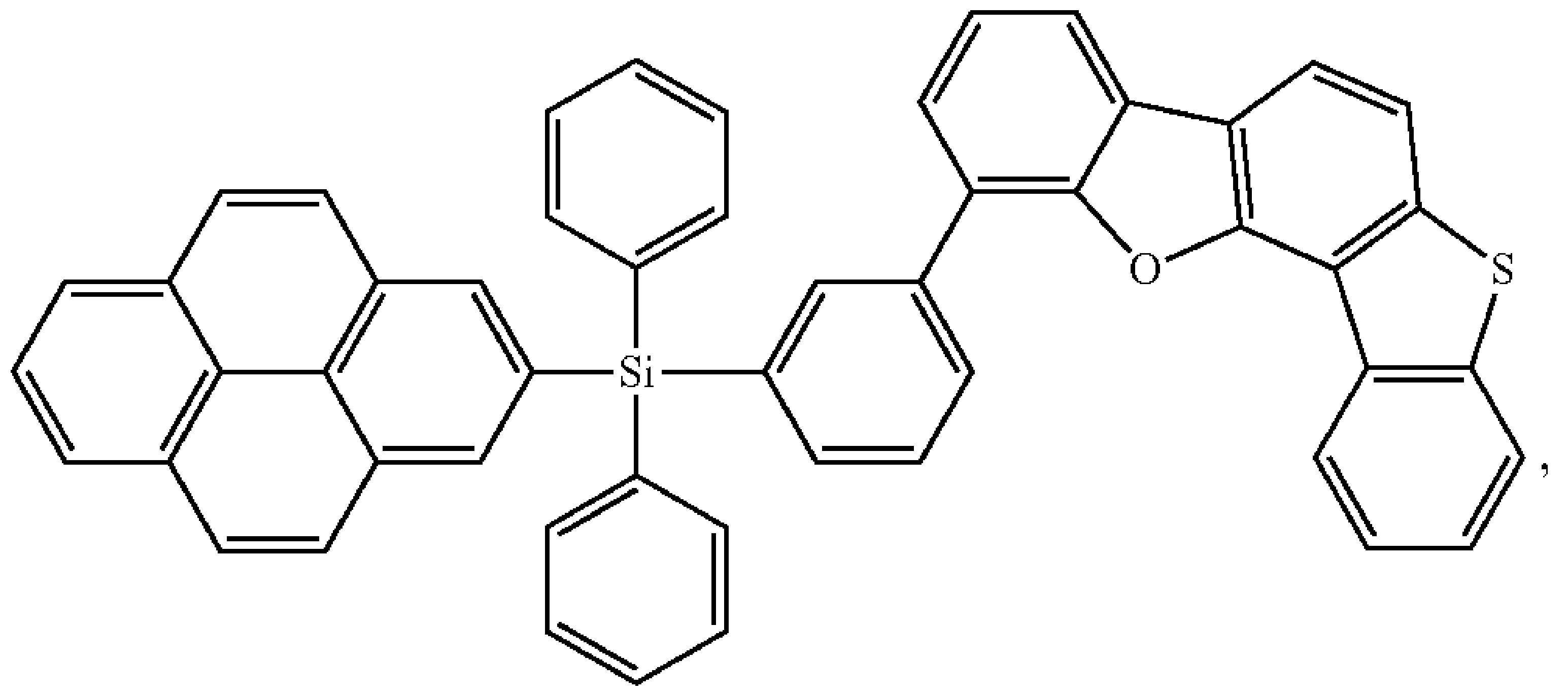

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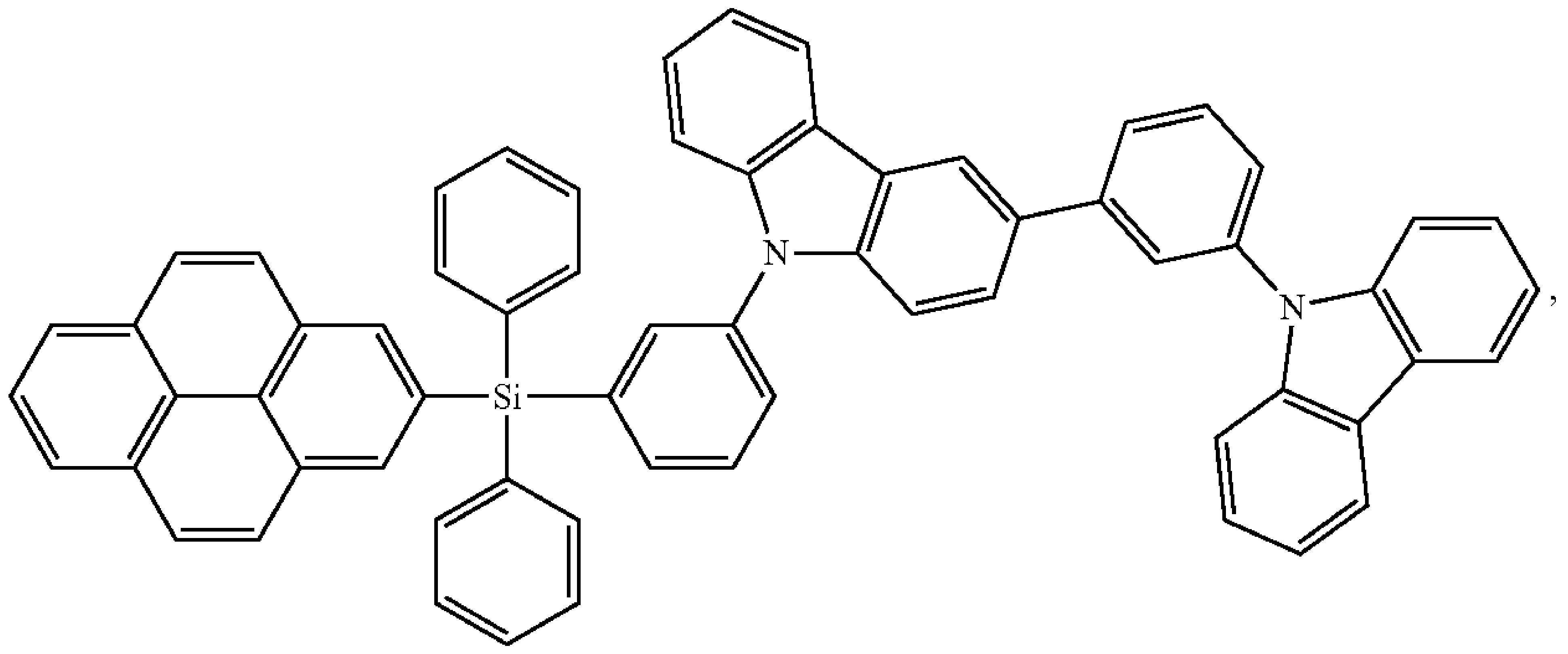

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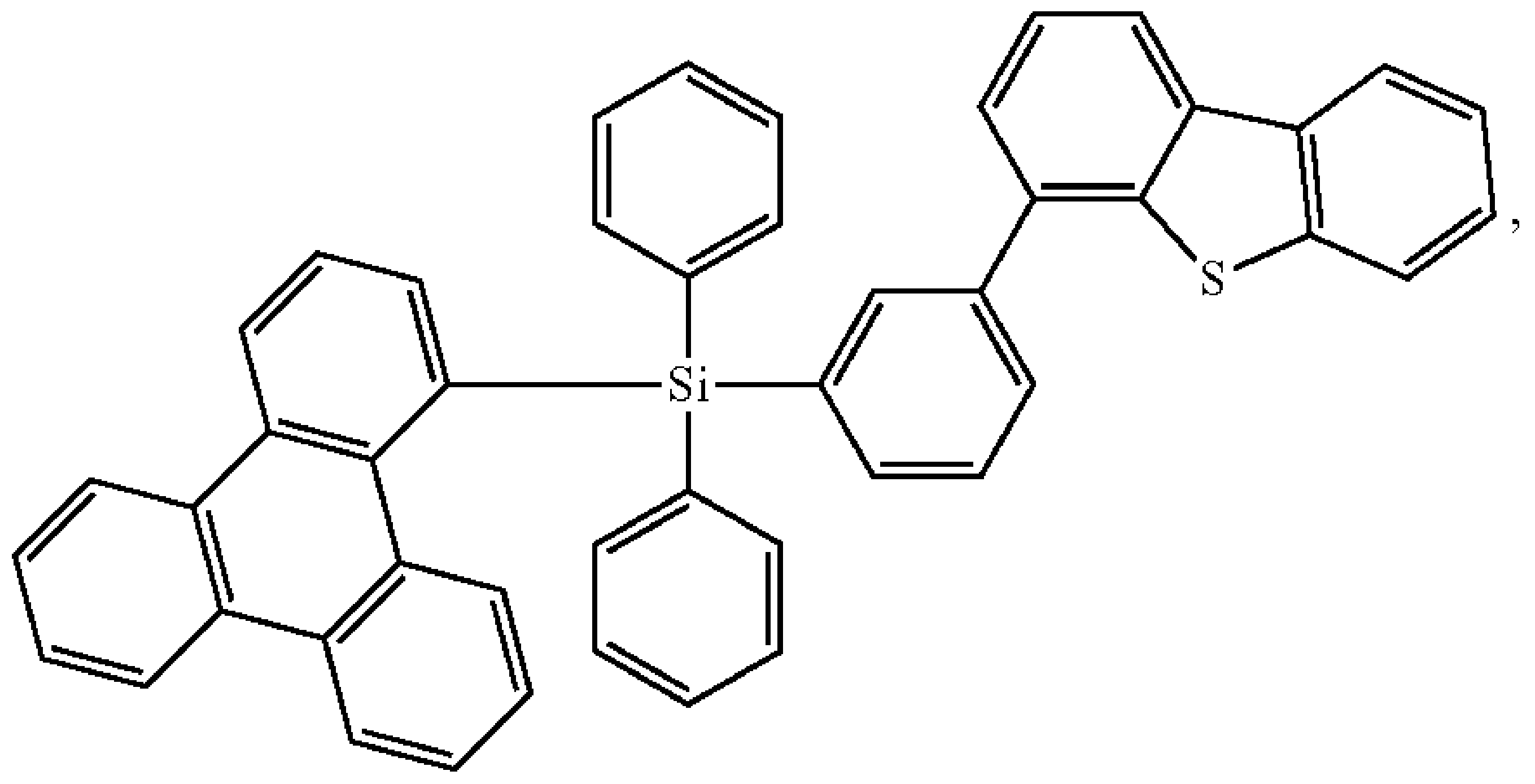

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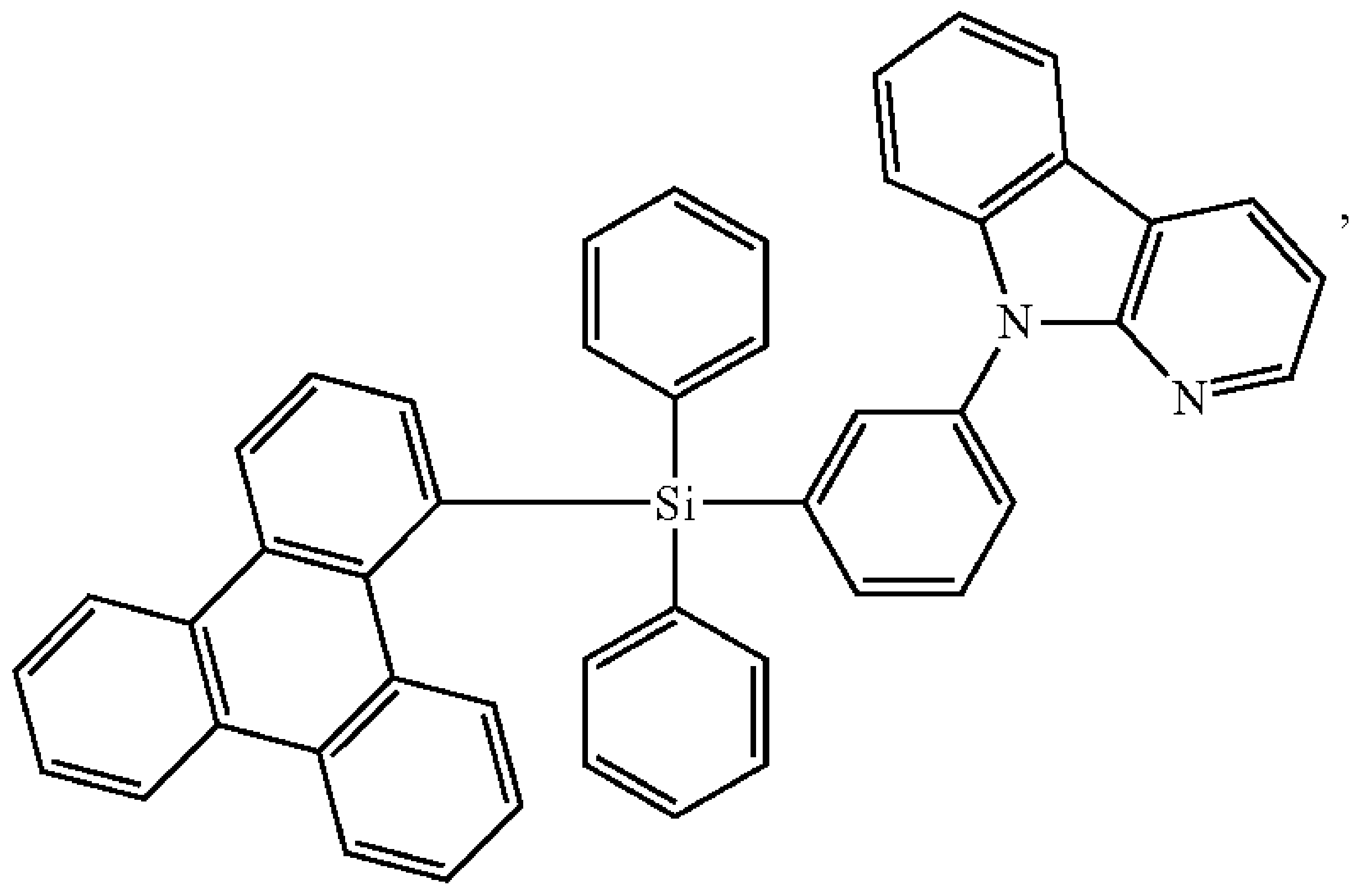

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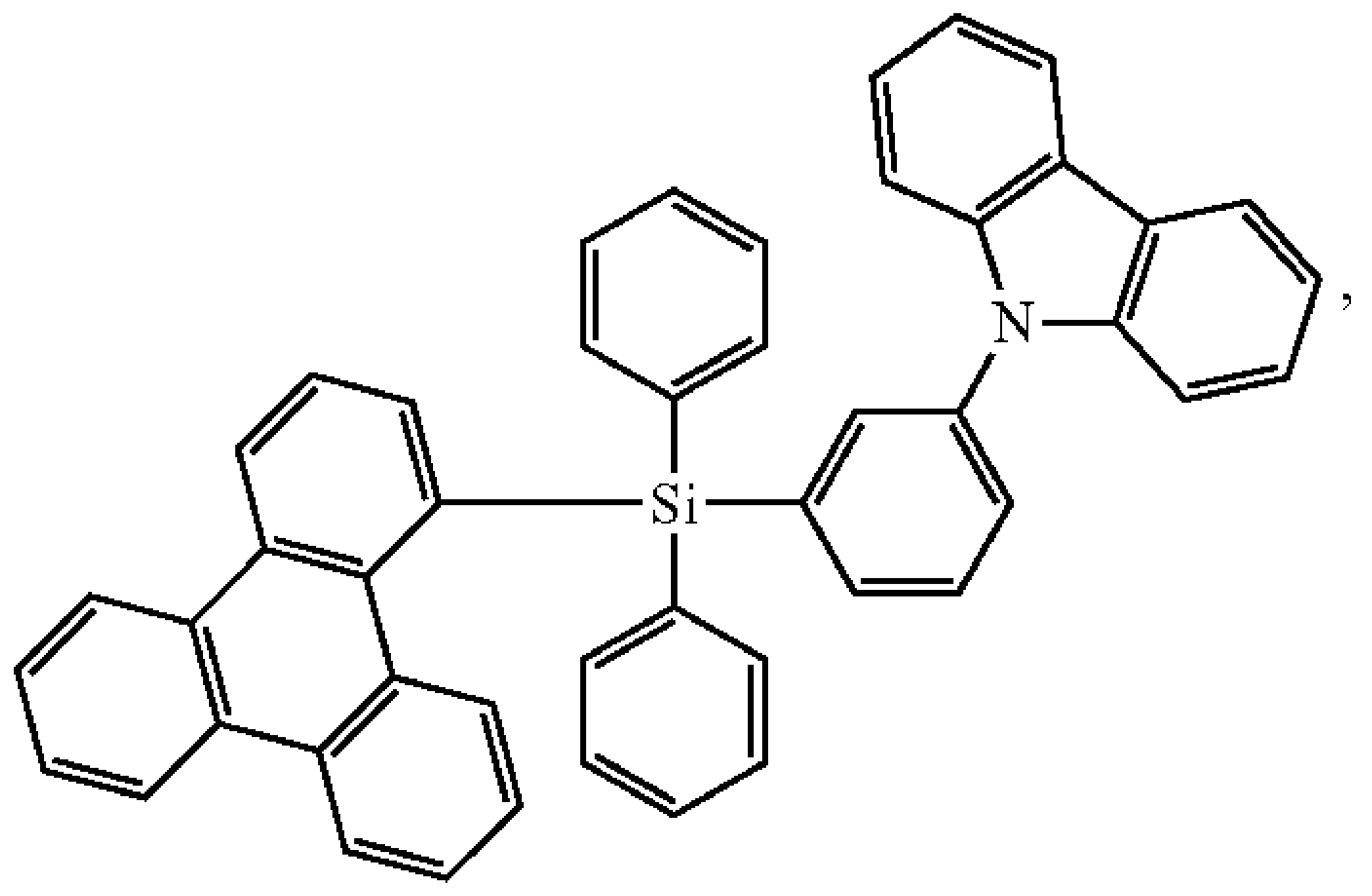
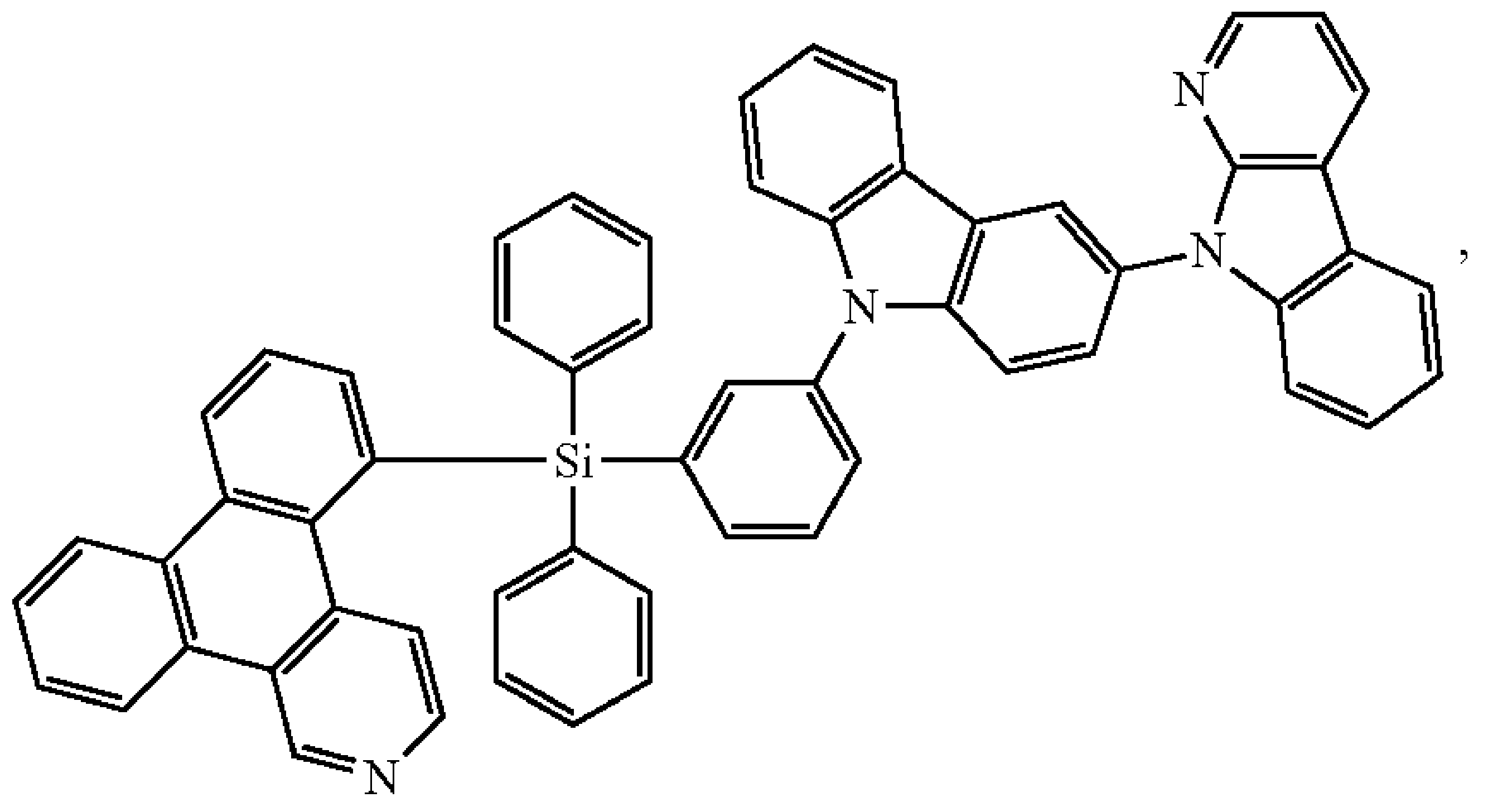


Compound 32



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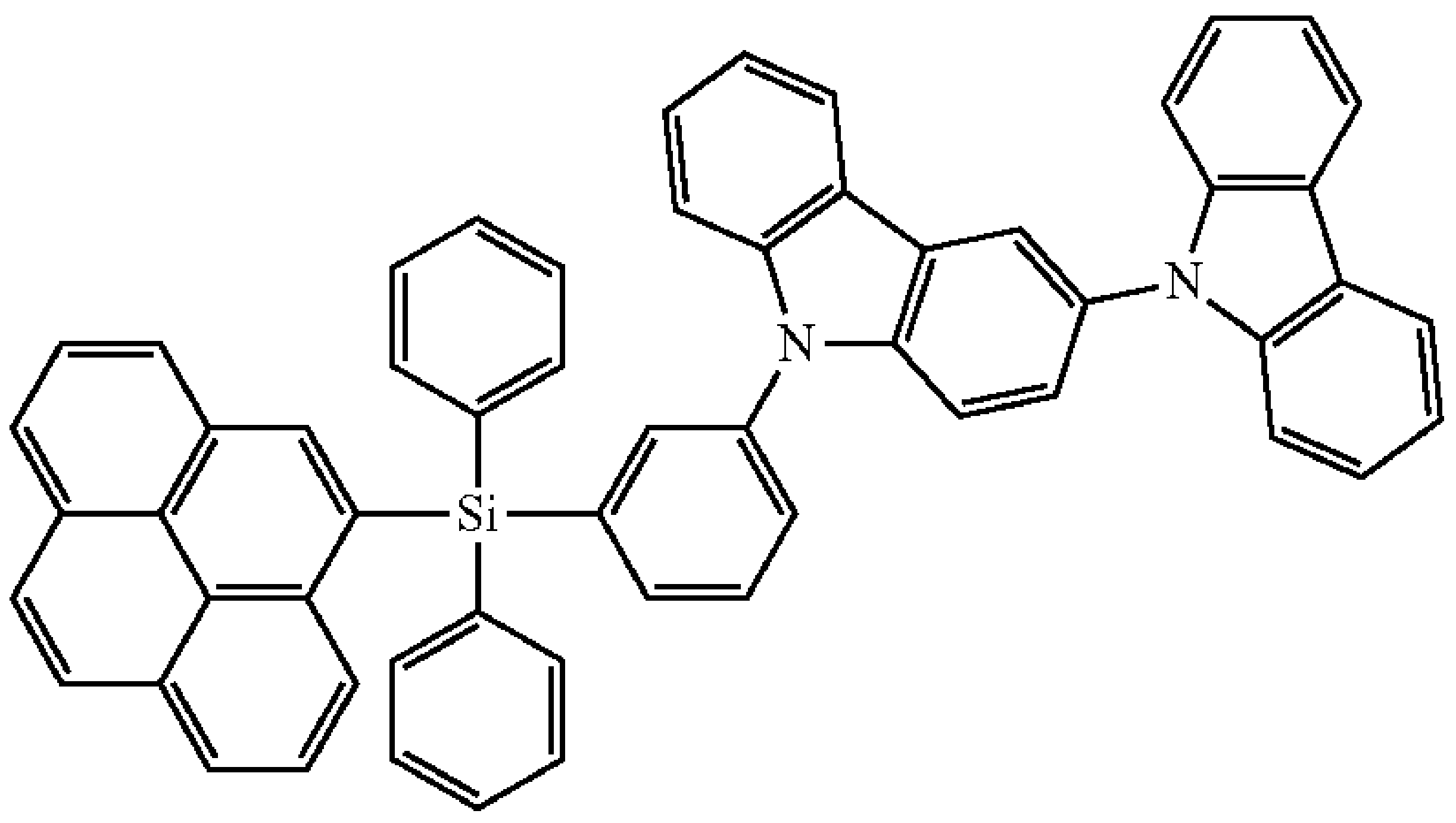
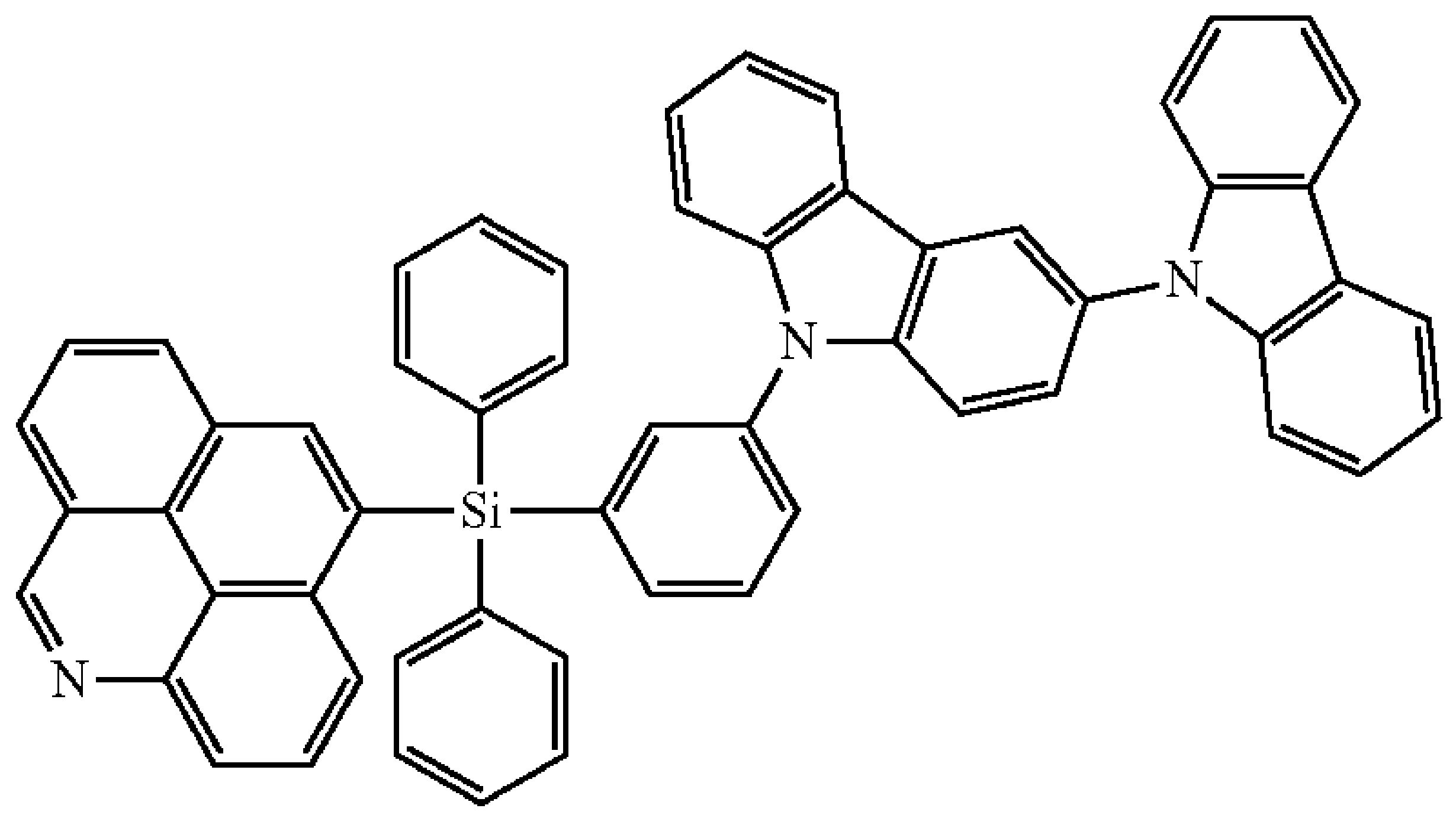
Compound 33



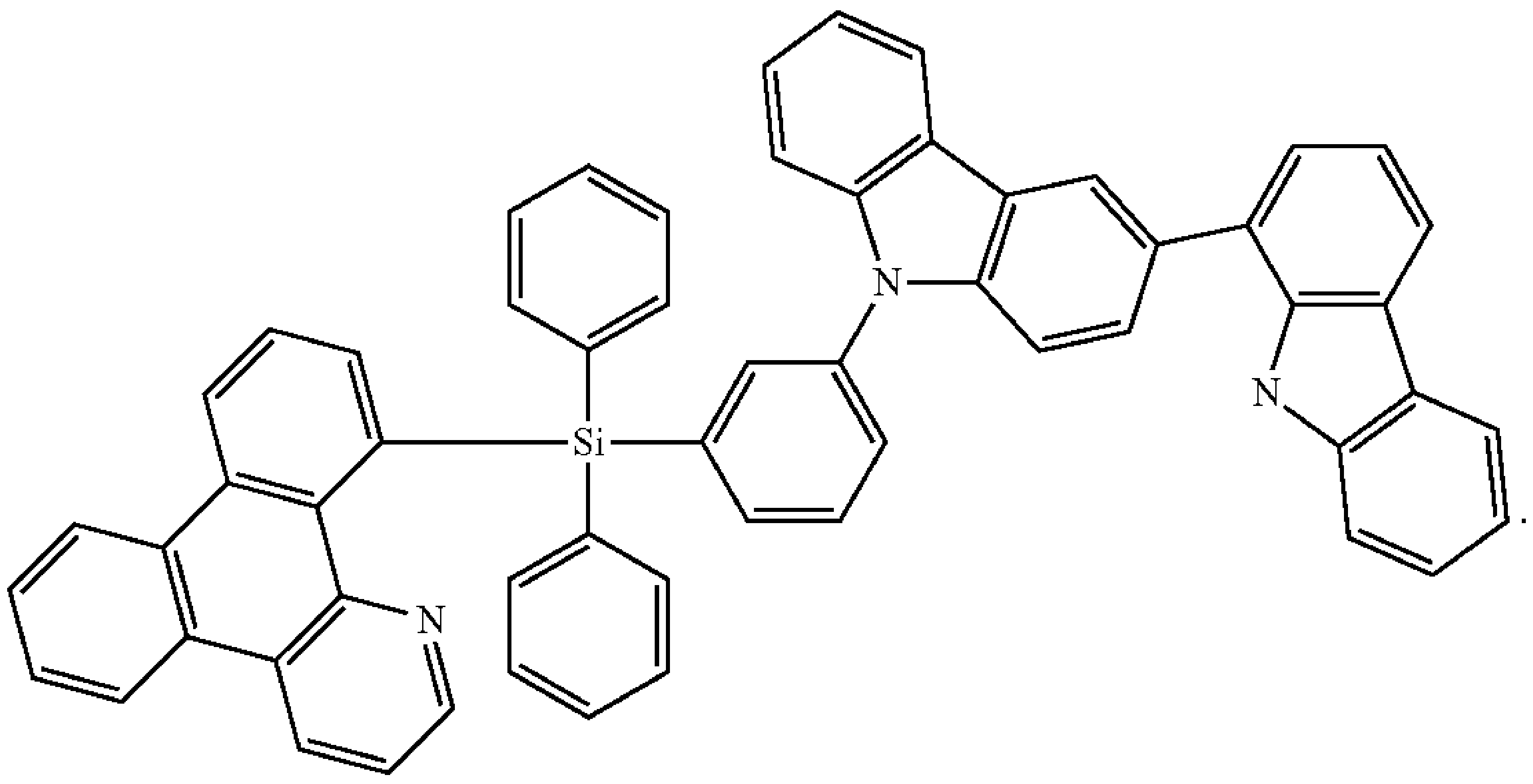
,

Compound 34



, and

Compound 35



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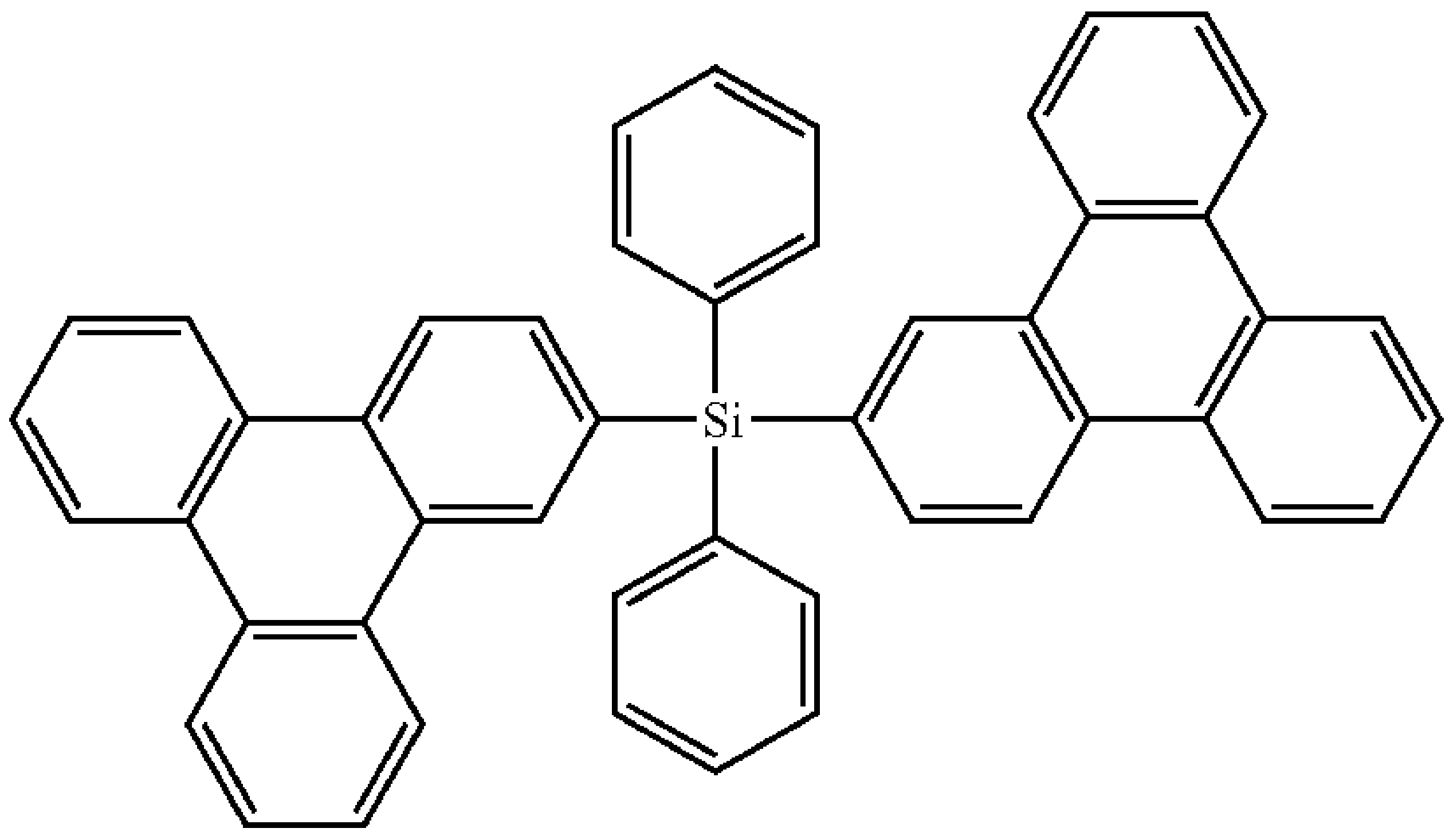
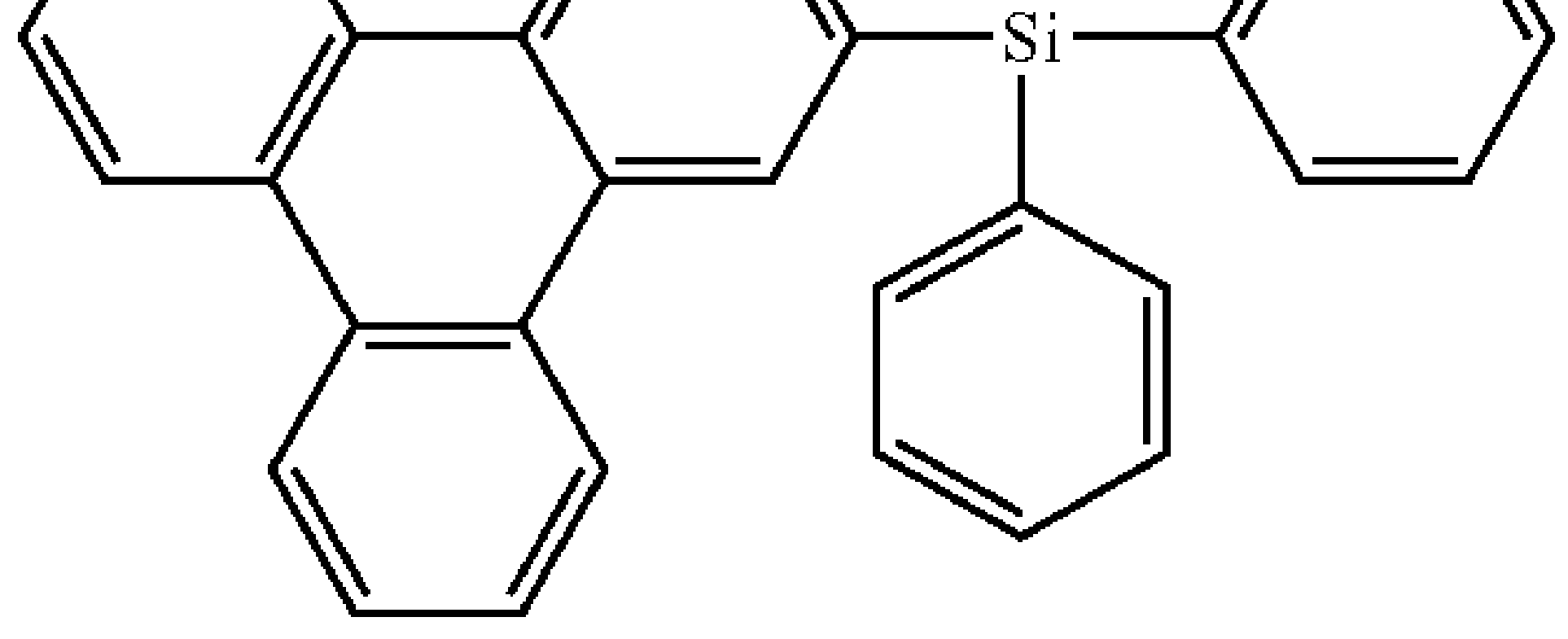
The structures of the Comparative Compounds described herein are as follows:

CC-1



CC-2



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CC-3

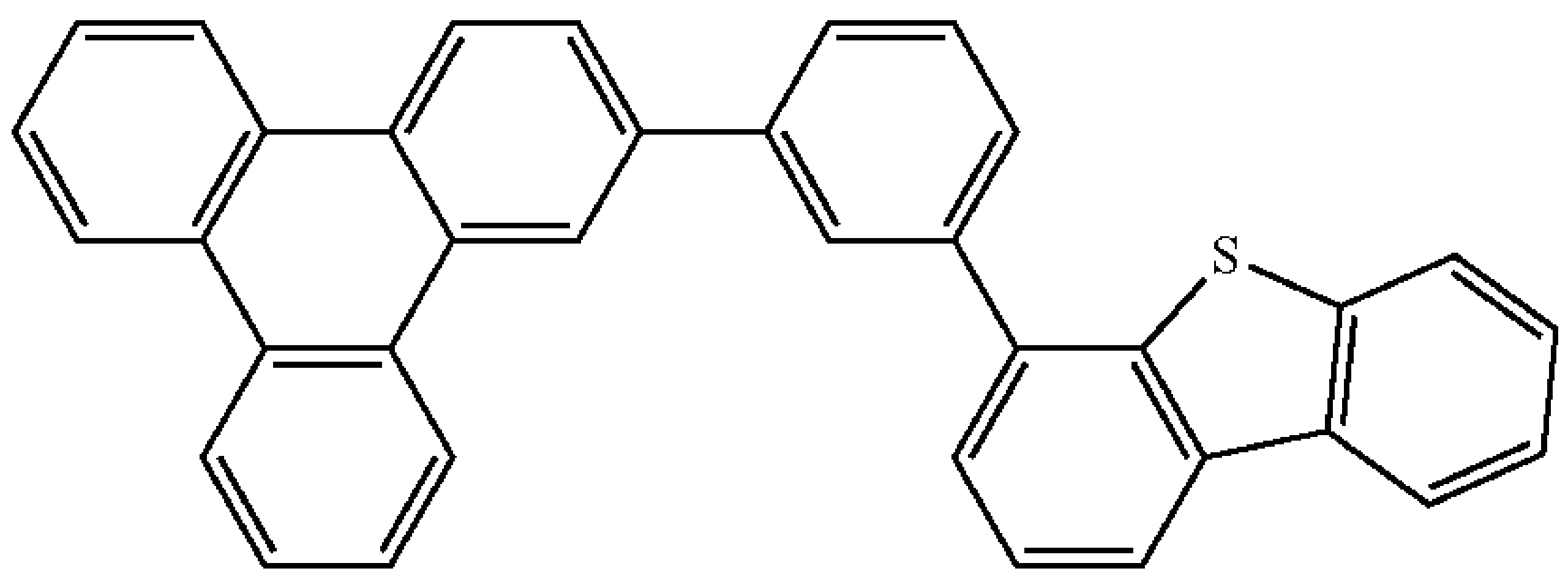


Table 1 lists the triplet energy levels for Compound 1-4 and Comparative Compounds CC-1 and CC-3. The triplet energy was measured from the maximum of the highest energy 0-0 vibronic band of the phosphorescence spectra collected in 10^{-4} M solution of the corresponding compound in 2-methyltetrahydrofuran at 77 K. While comparative compound CC-3, where triphenylene is connected with dibenzothiophene through a benzene unit, has a triplet energy of 2.64 eV, Compound 1 of Formula I, where a silane unit is inserted between triphenylene and the rest of the aromatic system, has a much higher triplet energy of 2.86 eV. This suggests that introduction of silane group is able to maintain a high triplet energy of triphenylene. This is also supported by the results of Compounds 2-4 and CC-1. A high triplet energy is required for the host materials to accommodate blue phosphorescent emitters.

TABLE 1

Selected Triplet Energy Levels for Compounds of Formula I and Comparison Compounds

Compound	Triplet energy, eV
Compound 1	2.86
Compound 2	2.86

TABLE 1-continued

Selected Triplet Energy Levels for Compounds of Formula I and Comparison Compounds

Compound	Triplet energy, eV
Compound 3	2.86
Compound 4	2.86
CC-1	2.88
CC-3	2.64

Table 2 lists the HOMO/LUMO energy levels for selected compounds of Formula I and Comparative Compound CC-1. The HOMO/LUMO levels were measured by differential pulse voltammetry in DMF solutions at a concentration of 10^{-3} M, with 0.1 M tetrabutylammonium hexafluorophosphate as the supporting electrolyte. A glass carbon disk, a platinum wire and a silver wire are used as the working, counter and pseudo reference electrodes, respectively. Ferrocene is added into the solution to serve as the internal standard for each measurement. The resultant oxidation potential (E_{ox}) and reduction potential (E_{red}), adjusted to ferrocene, are used to calculate the HOMO/LUMO levels as $-4.8\text{ eV}-qE_{ox}$ and $-4.8\text{ eV}-qE_{red}$, respectively, where q is the electron charge. All compounds have LUMO levels at about −2.1 eV, suitable for electron injection from adjacent electron transport layers. Though comparative compound CC-1 has a HOMO level below −6.00 eV, which is the measurement limit, the HOMO levels for compounds of Formula I could be tuned through variation of B group. Indeed, the HOMO levels of Compounds 3, 4 and 5 were found to be −5.67, −5.55 and −5.41 eV, respectively. It is noted that these HOMO levels are below commonly used triplet emitters, allowing efficient hole trapping in the device operation.

TABLE 2

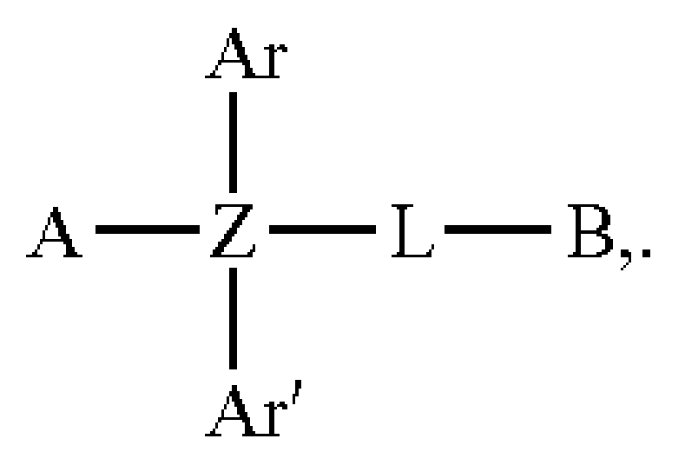
Selected HOMO/LUMO Energy Levels for Compounds of Formula I and Comparison Compounds

Compound	HOMO, eV	LUMO, eV
Compound 1	<−6.00	−2.08
Compound 2	<−6.00	−2.06
Compound 3	−5.67	−2.08
Compound 4	−5.55	−2.07
Compound 5	−5.41	−2.04
CC-1	<−6.00	−2.05

FIG. **5** shows the differential scanning calorimetry (DSC) curves for selected compounds of Formula I and for Comparative Compounds CC-1 and CC-2. Samples were thermally vaporized under vacuum at a pressure less than 10^{-5} Torr and condensed in a zone 100° C. cooler than the vaporization zone. The condensed samples were gradually cooled to room temperature before subjecting to DSC measurement where the reported first heating scans were recorded at 10° C./min under nitrogen atmosphere. With asymmetric structures, compounds of Formula I are amorphous with stable morphological stability. During heating from 30° C. to 330° C., Compounds 1, 3 and 4 undergo glass transitions at 103, 101, and 144° C., respectively, without encountering any crystallization or melting. Compound 2 shows a small melting peak at 212° C. with a small melting enthalpy of 2 J/g due to residual crystals embedded in an amorphous bulk. On the other hand, CC-1 with a symmetric structure encounters a pronounced melting peak at 243° C. with a melting enthalpy of 58 J/g, suggesting the presence of significant crystals. Furthermore, CC-2 comprising a simple triphenylsilyl group attached to triphenylene is highly crystalline with a melting peak at 207° C. accompanied by a melting enthalpy of 75 J/g. In fact, CC-2 does not undergo any glass transition during the first heating scan, suggesting the absence of amorphous phase and complete crystallinity. These DSC results demonstrated that the asymmetric structure according to this invention is effective in suppressing crystallization and is conducive to a stable amorphous morphology, which is beneficial to device operational stability.

In one embodiment, a first device is provided. The first device comprises an organic light-emitting device, which further comprises an anode, a cathode, and an organic layer, disposed between the anode and the cathode, comprising a compound having the Formula I:

Formula I



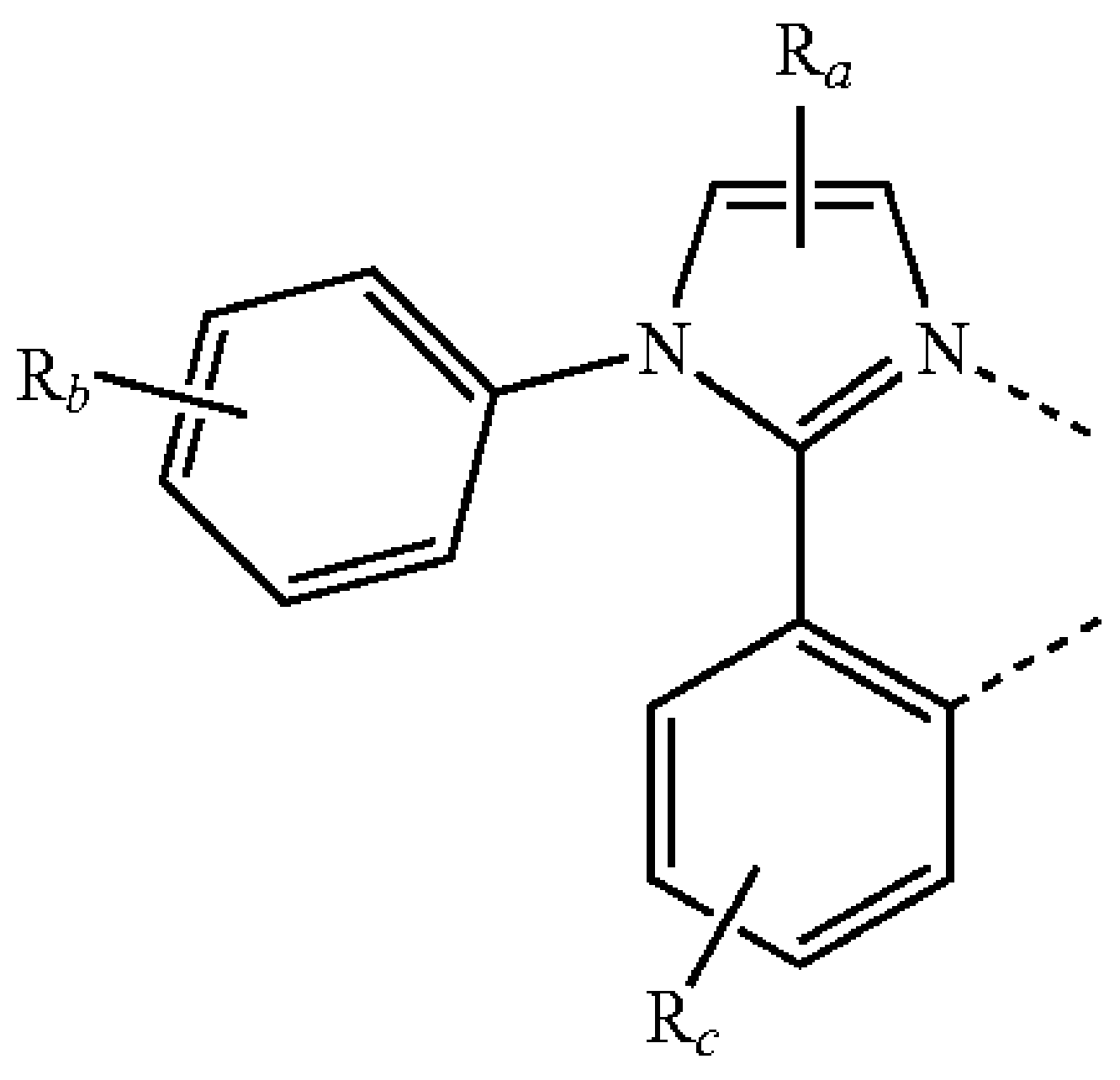
$$A-\underset{Ar'}{\overset{Ar}{Z}}-L-B,.$$

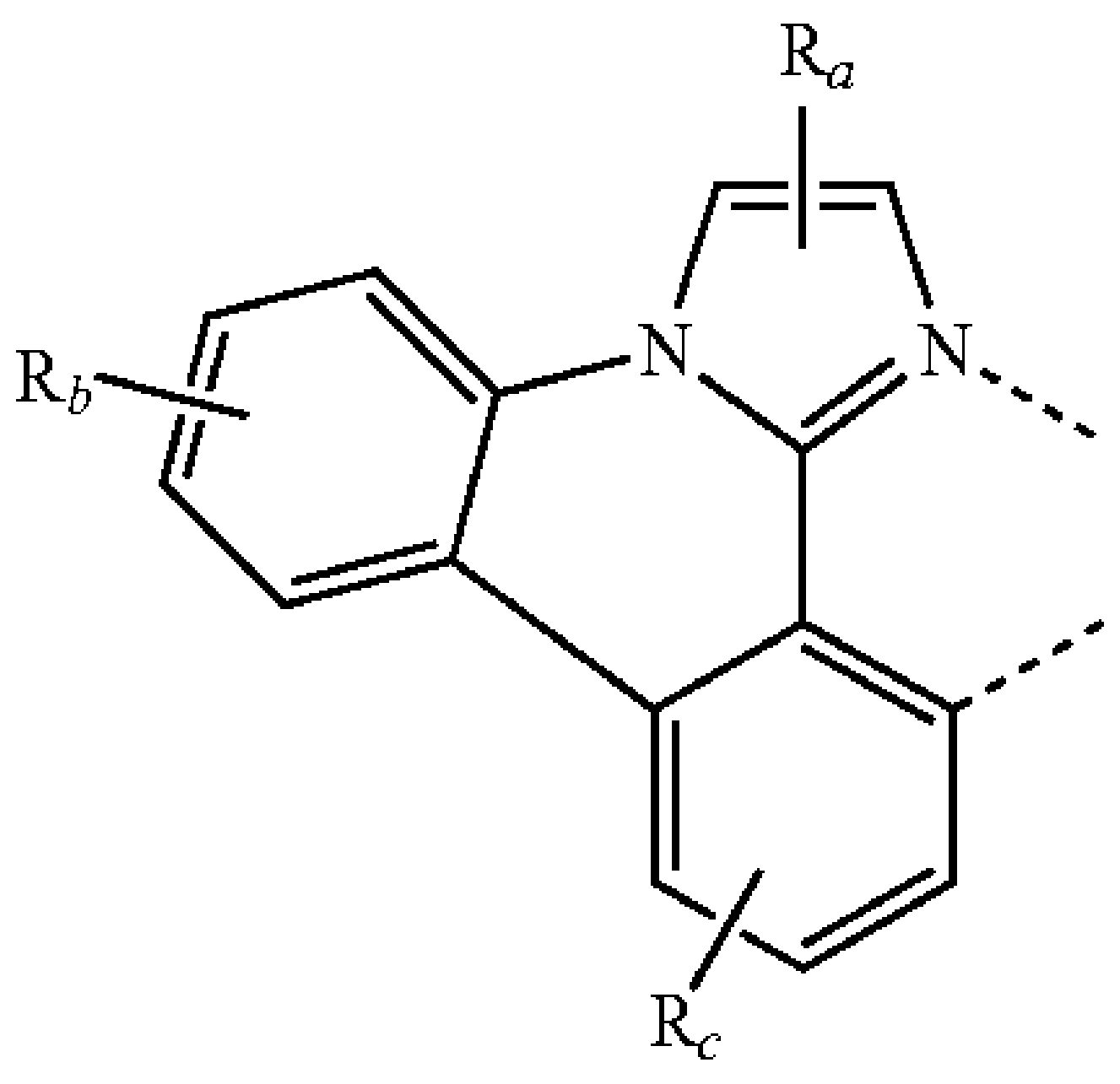
In the compound of Formula I, Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, naphthalene, dibenzothiophene and dibenzofuran, which are optionally further substituted. Z is selected from Si and Ge. L is a single bond or comprises an aryl or heteroaryl group having from 5-20 carbon atoms, which is optionally further substituted. A is a group directly bonded to Z and is selected from the group consisting of triphenylene, tetraphenylene, pyrene, naphthalene, fluoranthene, chrysene, phenanthrene, azatriphenylene, azatetraphenylene, azapyrene, azanaphthalene, azafluoranthene, azachrysene, azaphenanthrene, and combinations thereof, which are optionally further substituted with one or more groups selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof.

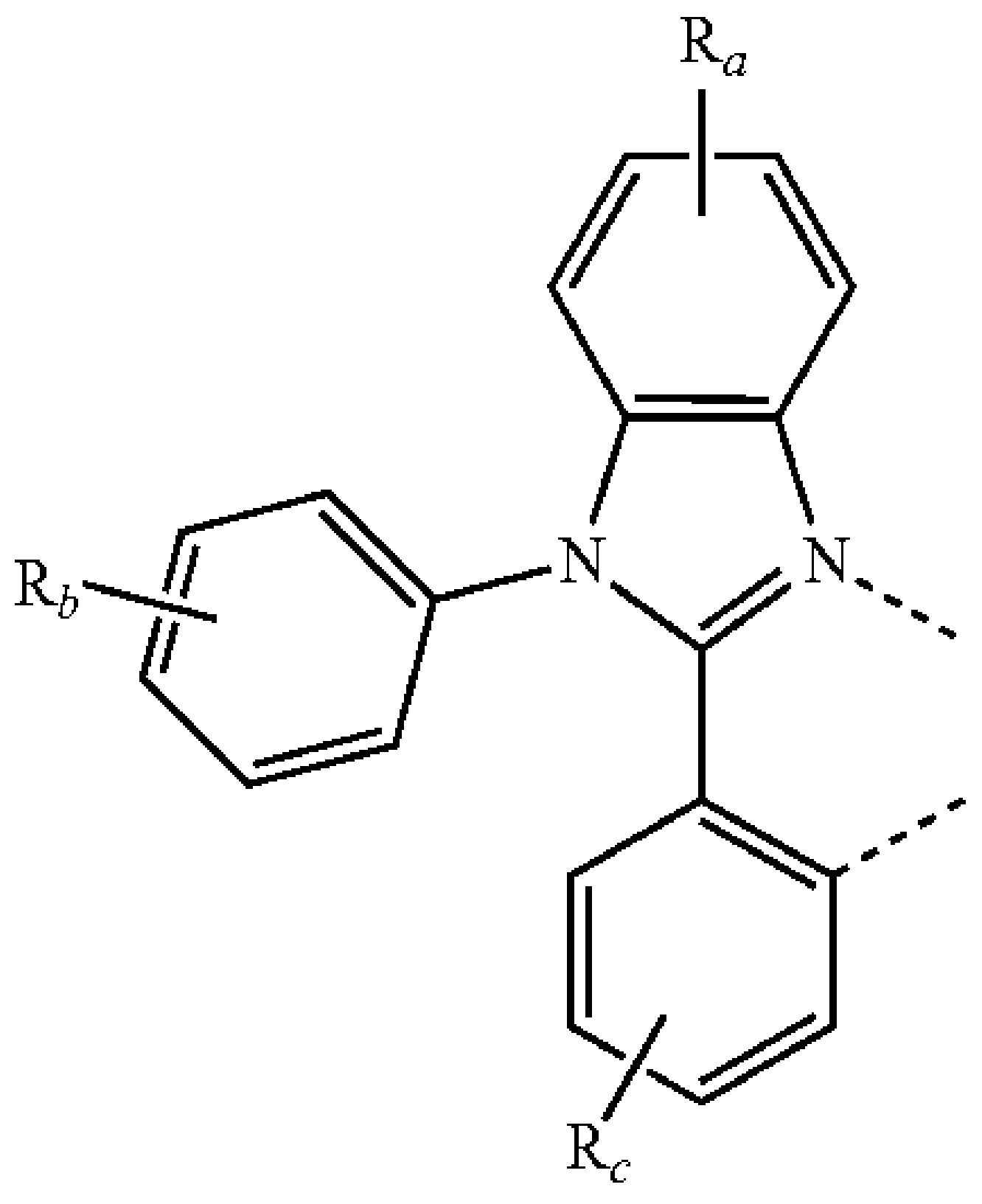
B contains a group selected from the group consisting of carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene, azadibenzoselenophene, and combinations thereof, which are optionally further substituted with one or more groups selected from hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, and wherein the substitution is optionally fused to the carbazole, dibenzofuran, dibenzothiophene, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene or azadibenzoselenophene group.

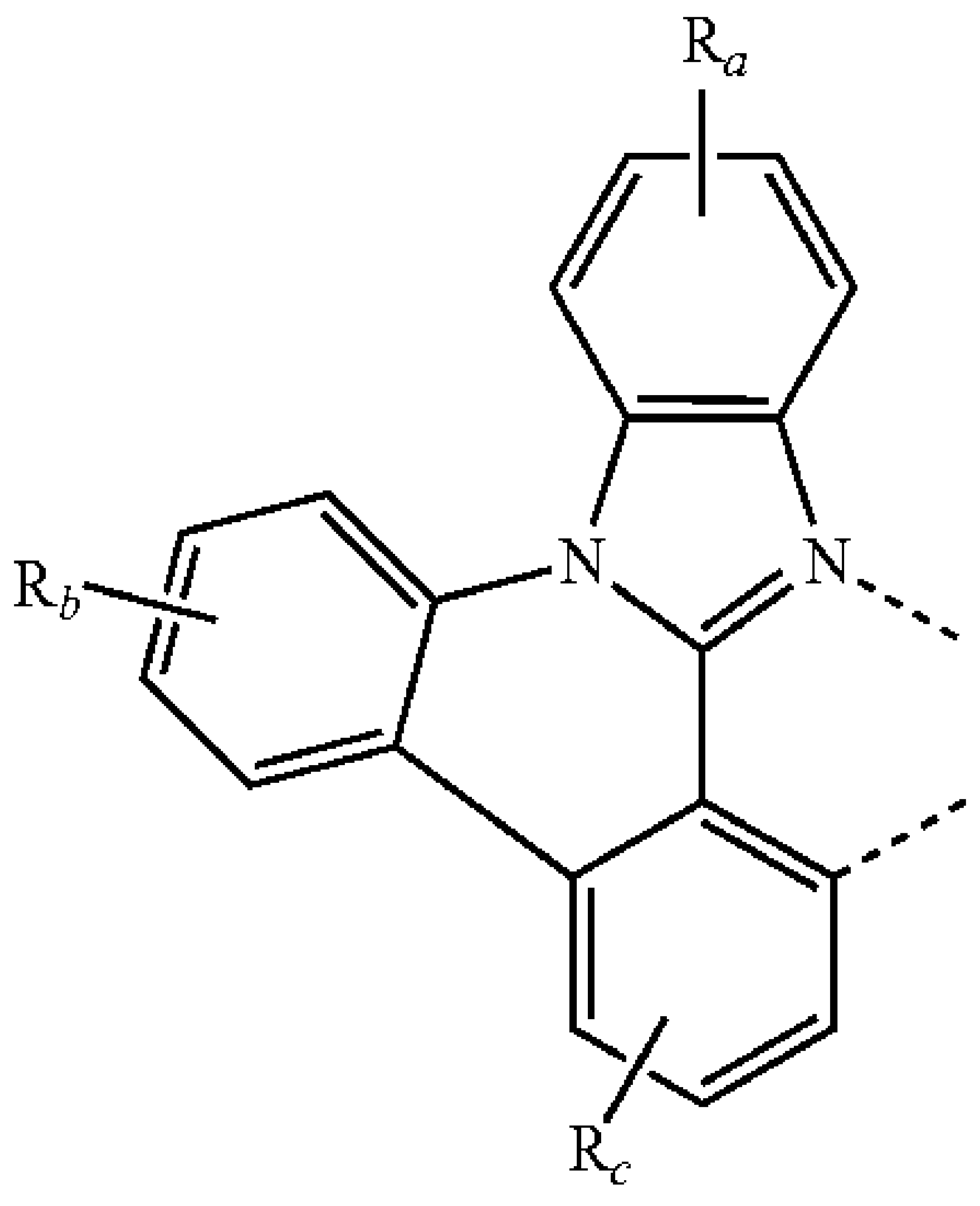
In one embodiment, the organic layer is an emissive layer and the compound of Formula I is a host. In another aspect, the organic layer further comprises an emissive dopant.

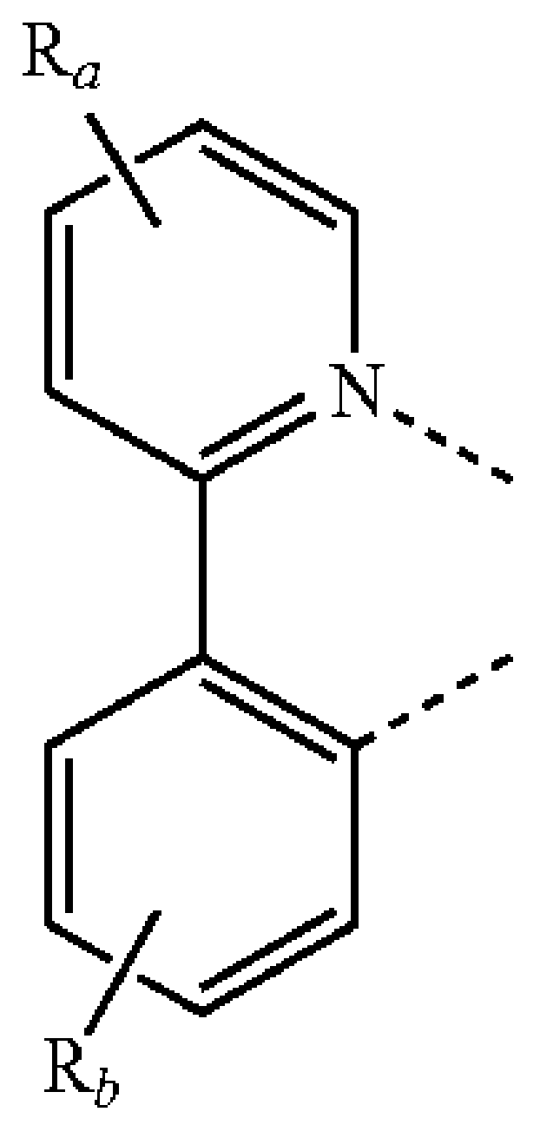
In one embodiment, the emissive dopant is a transition metal complex having at least one ligand selected from the group consisting of:

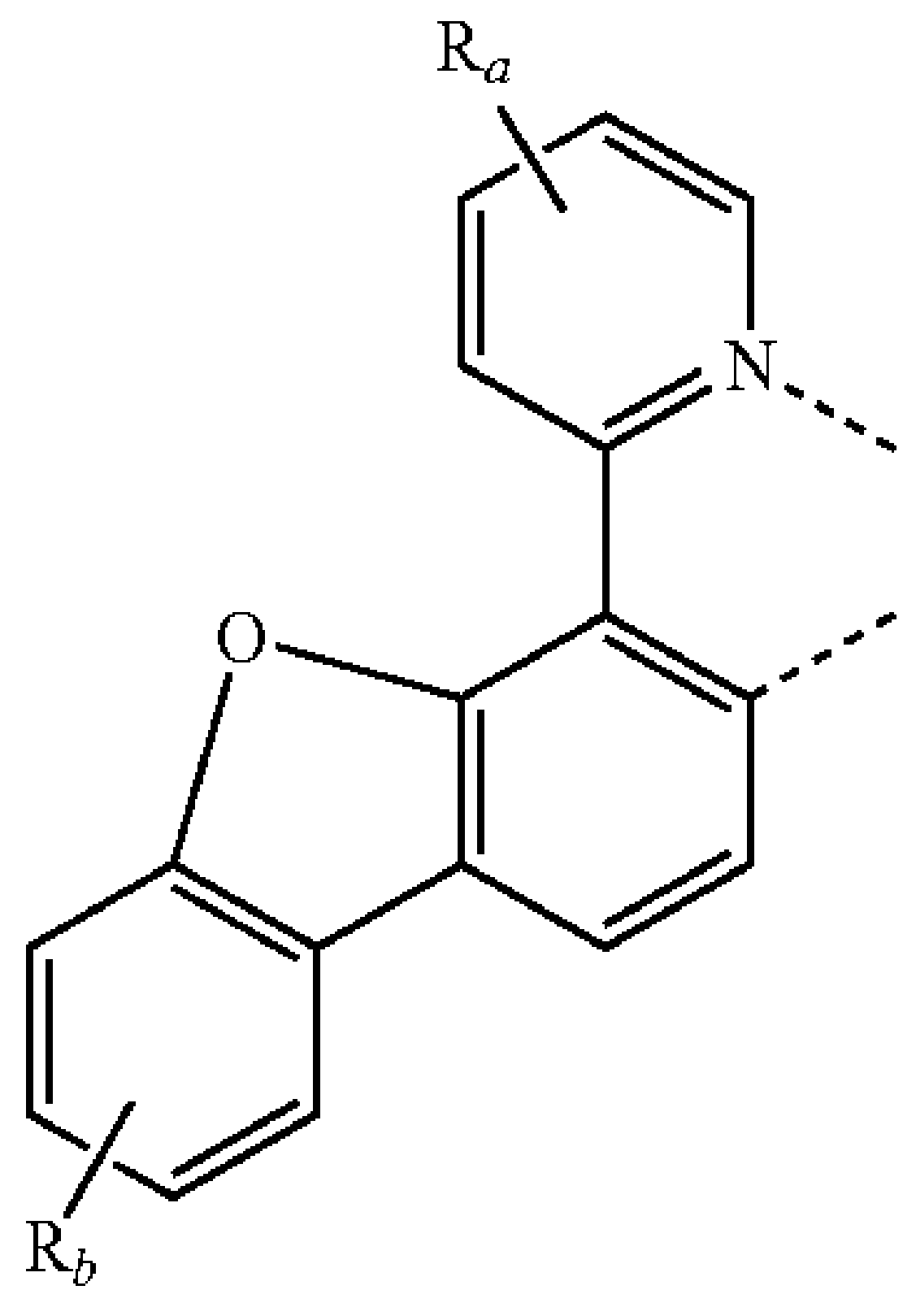


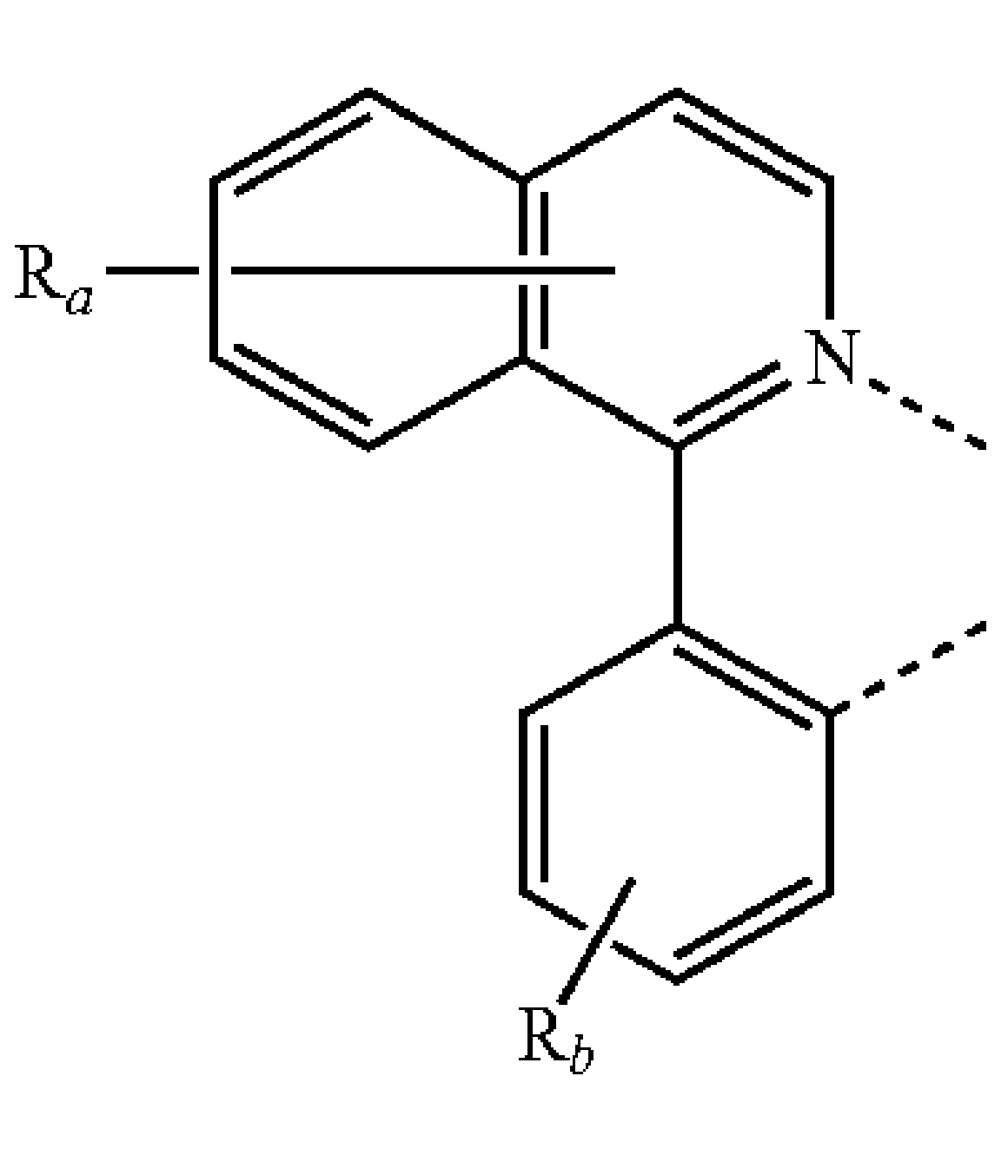


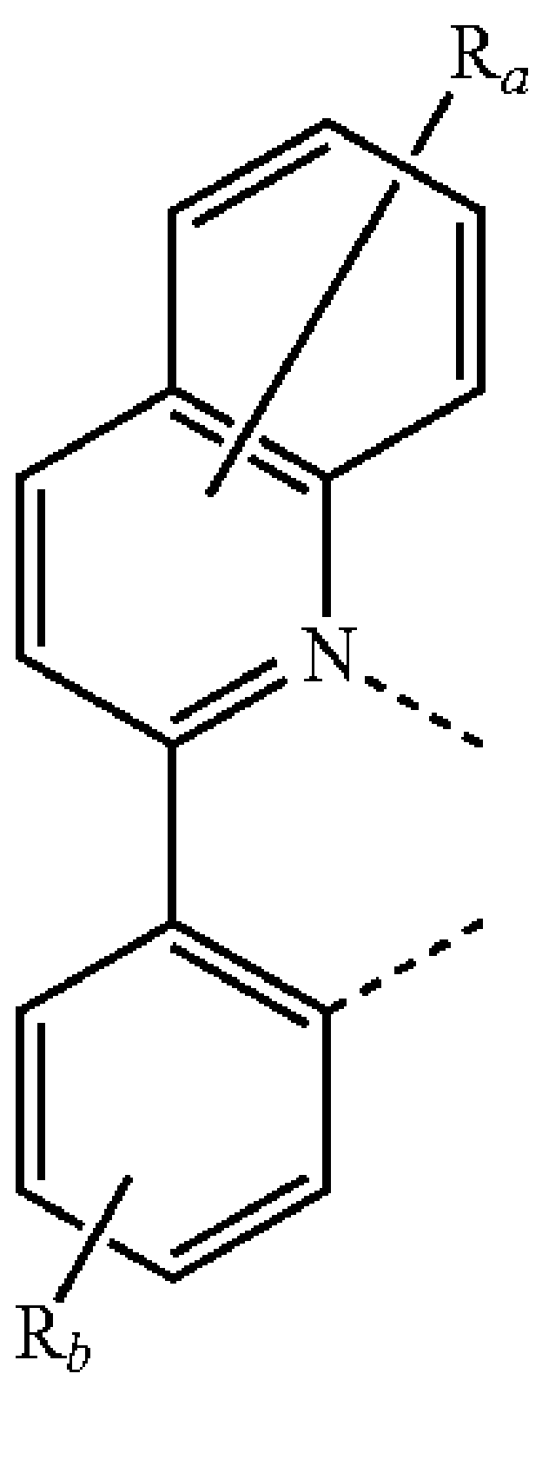


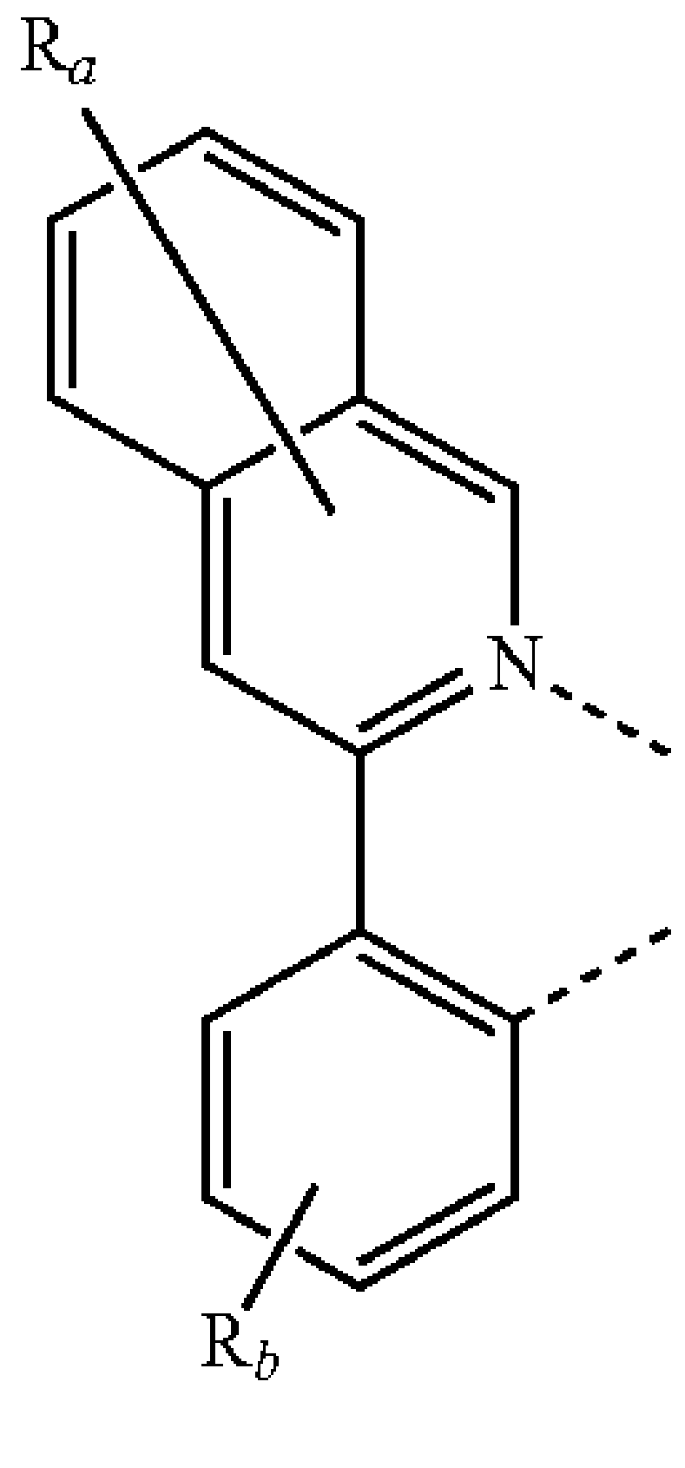


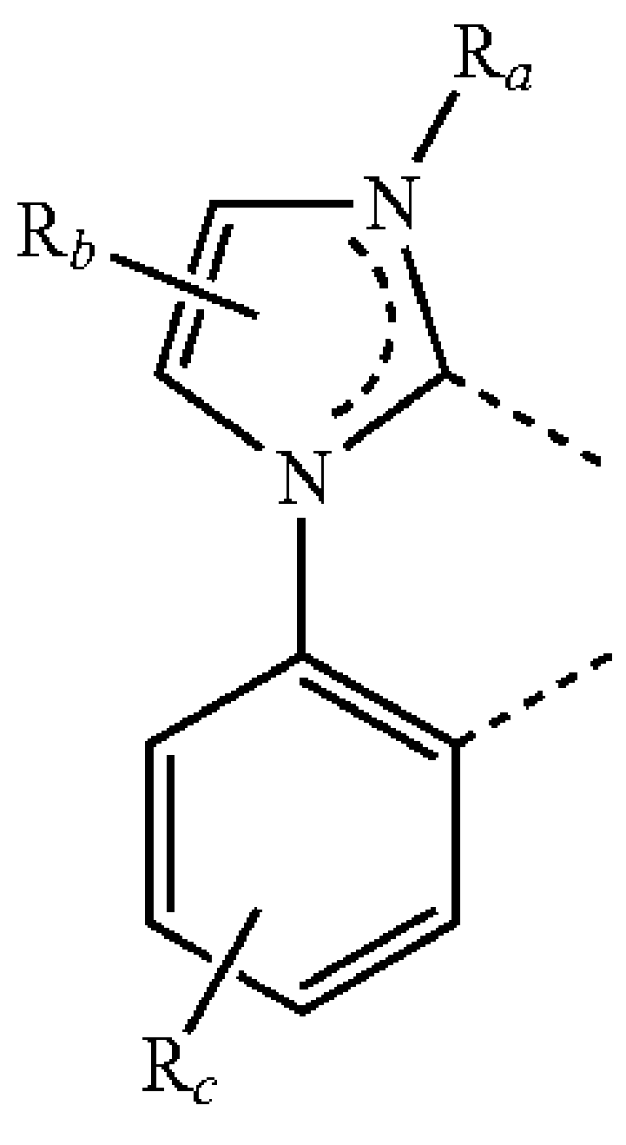


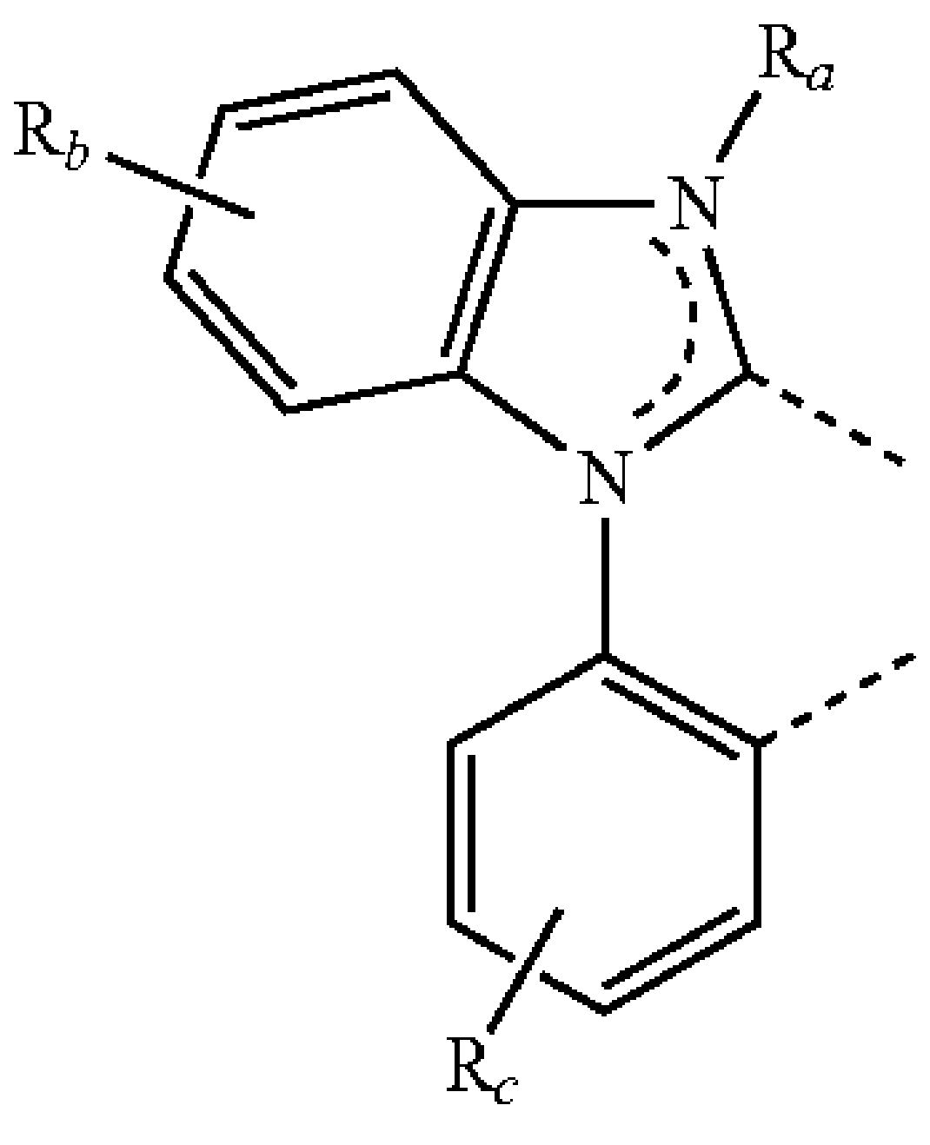












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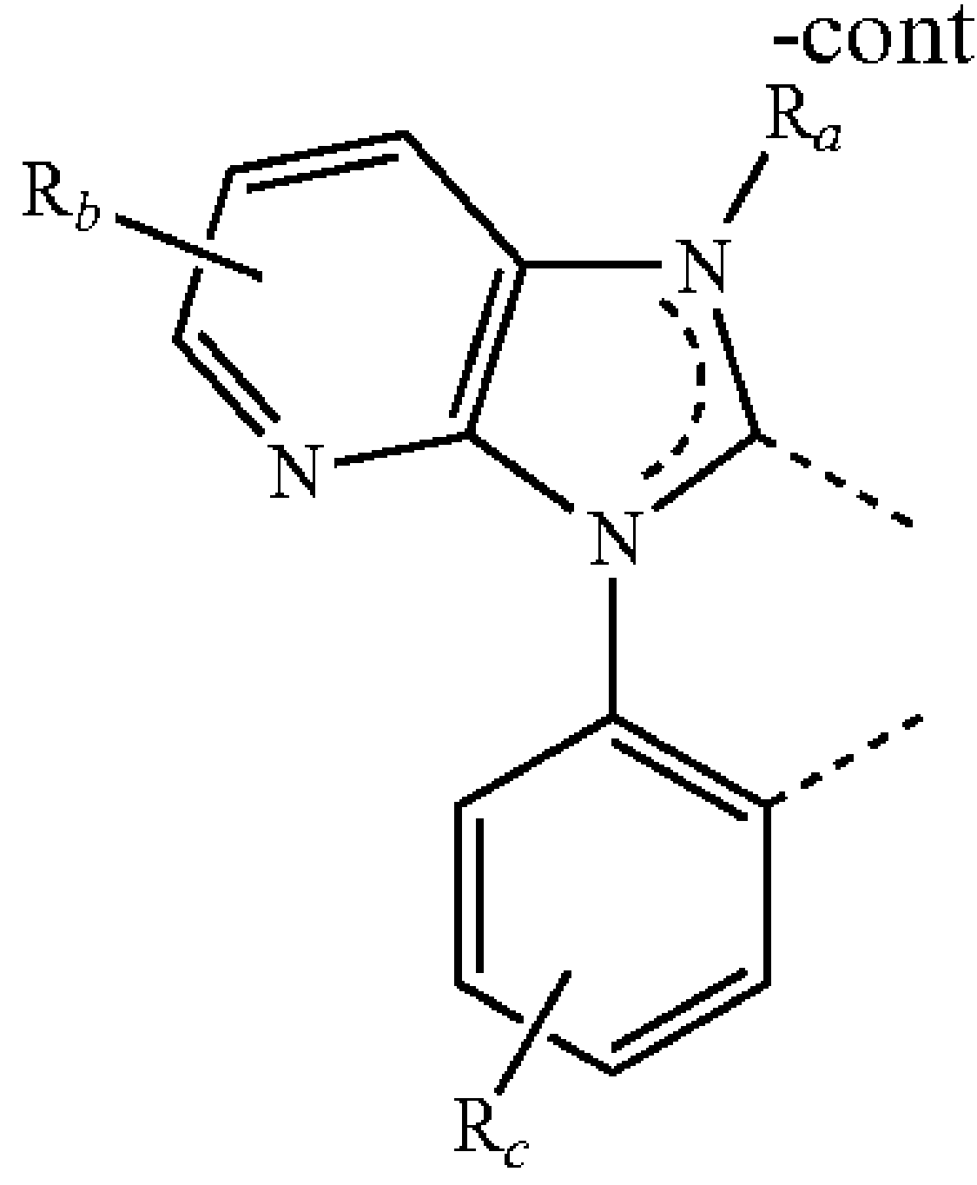
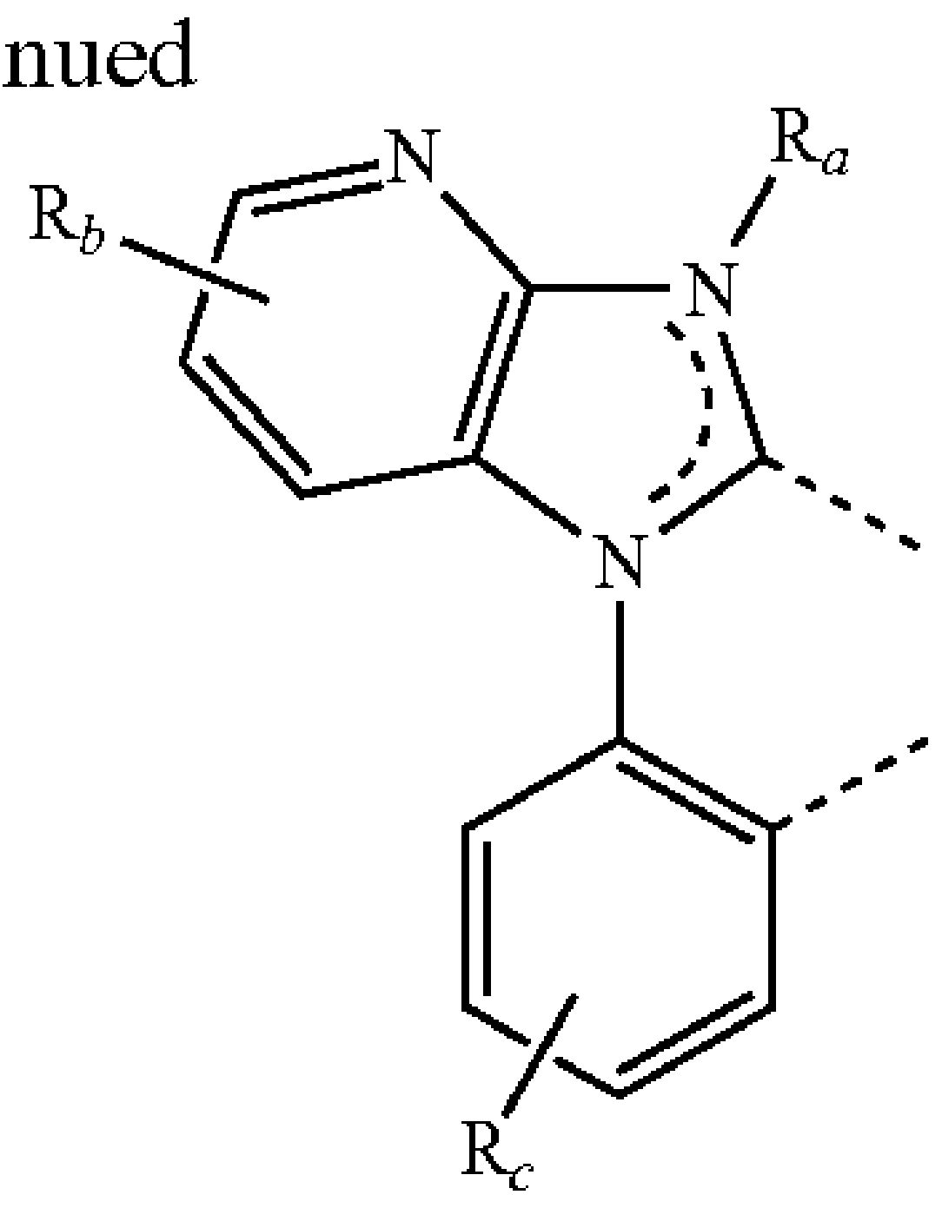
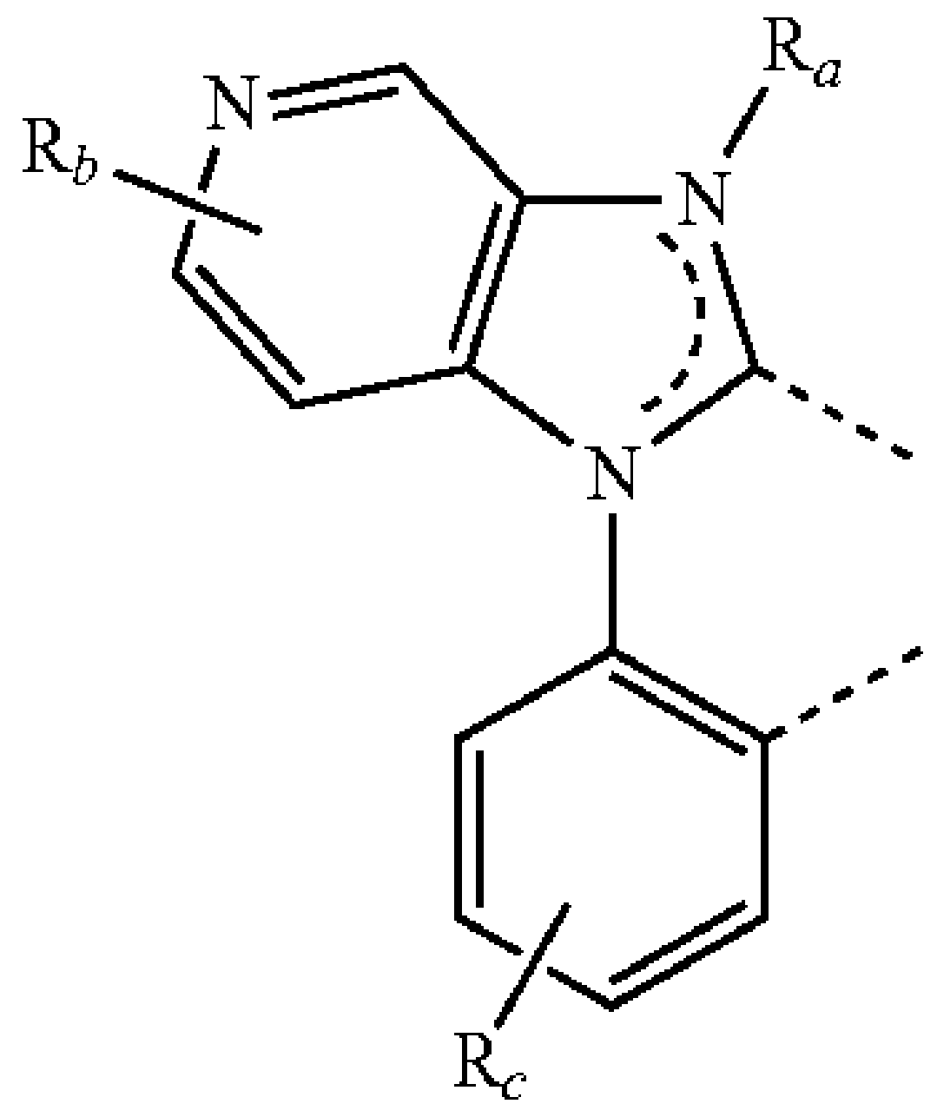
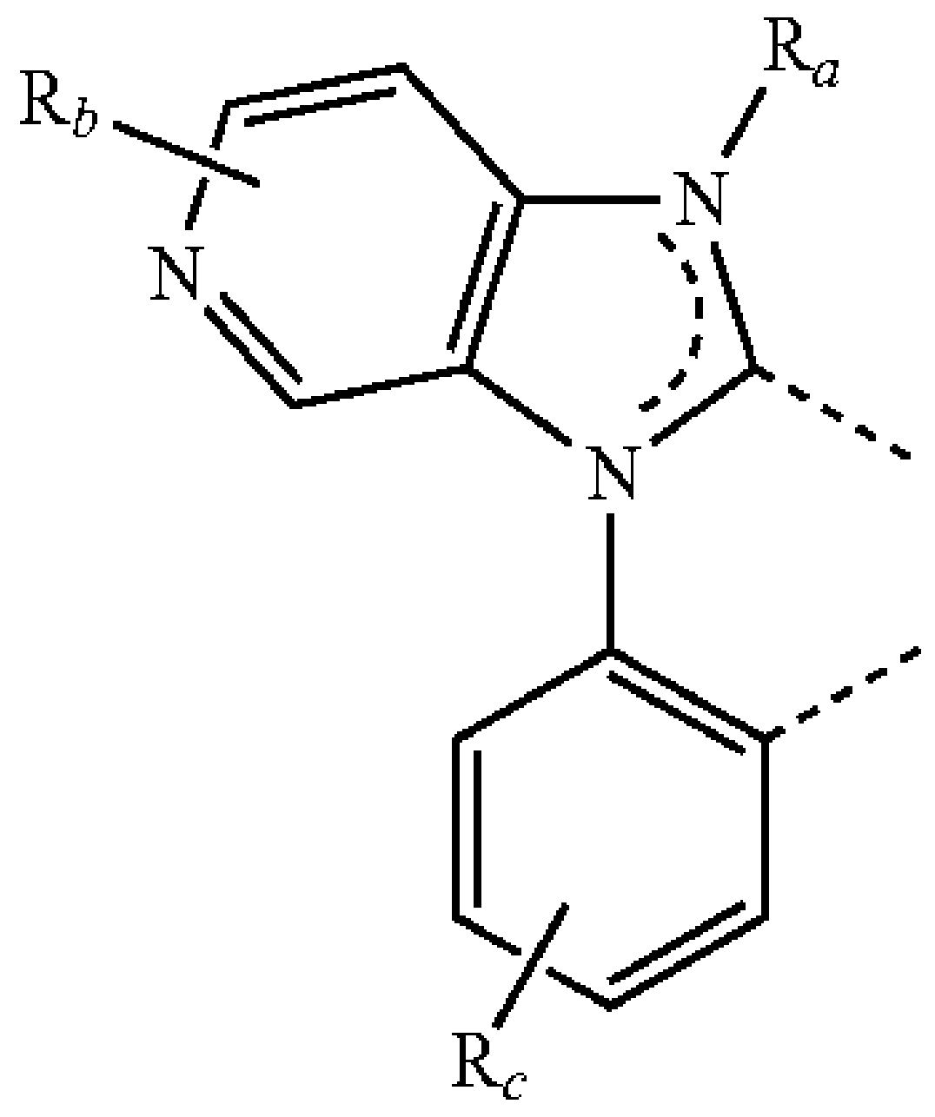
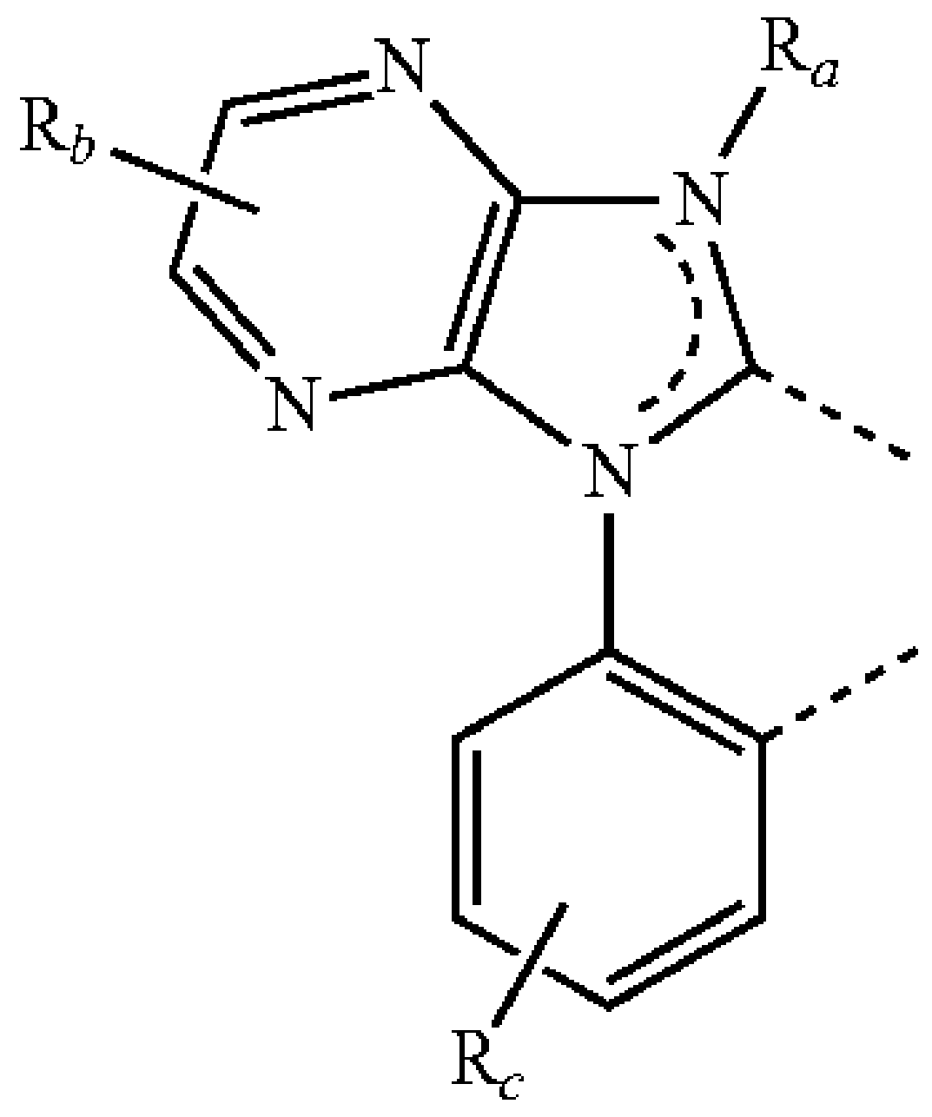
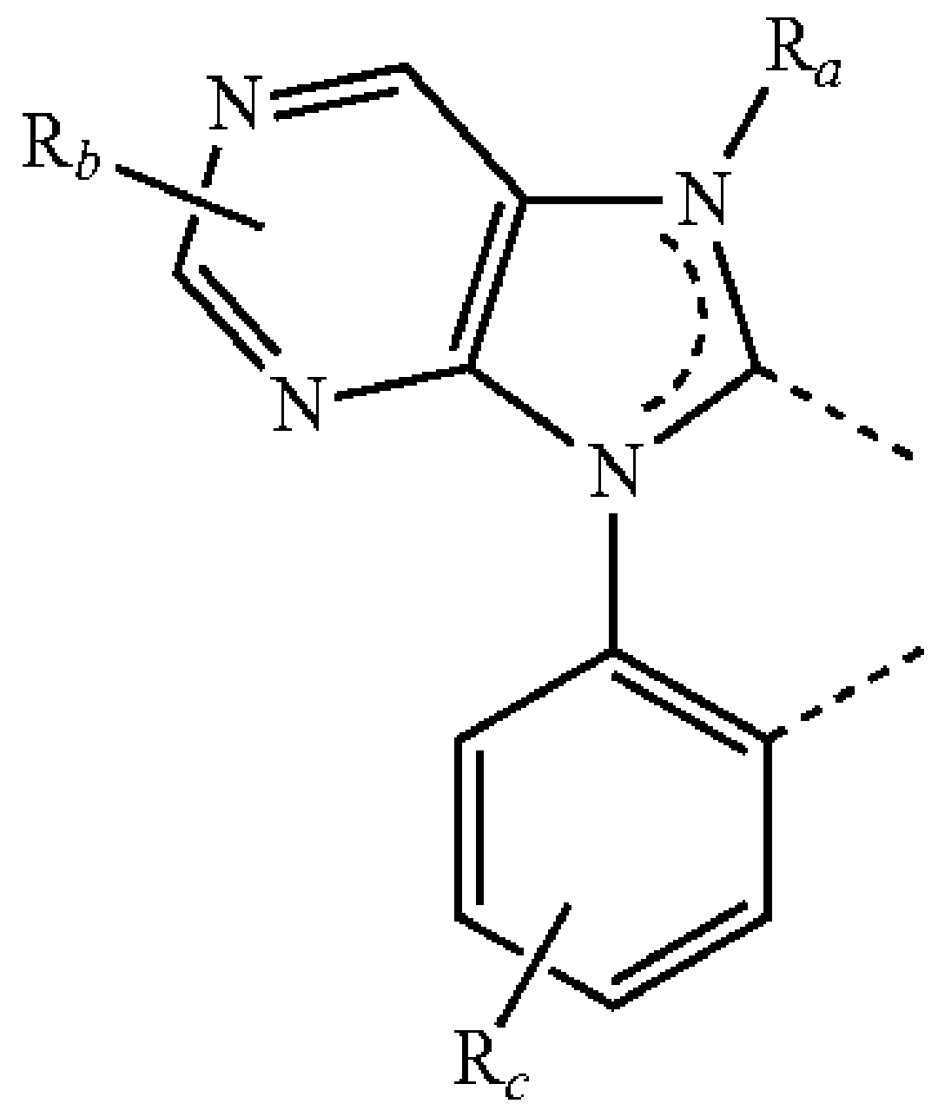


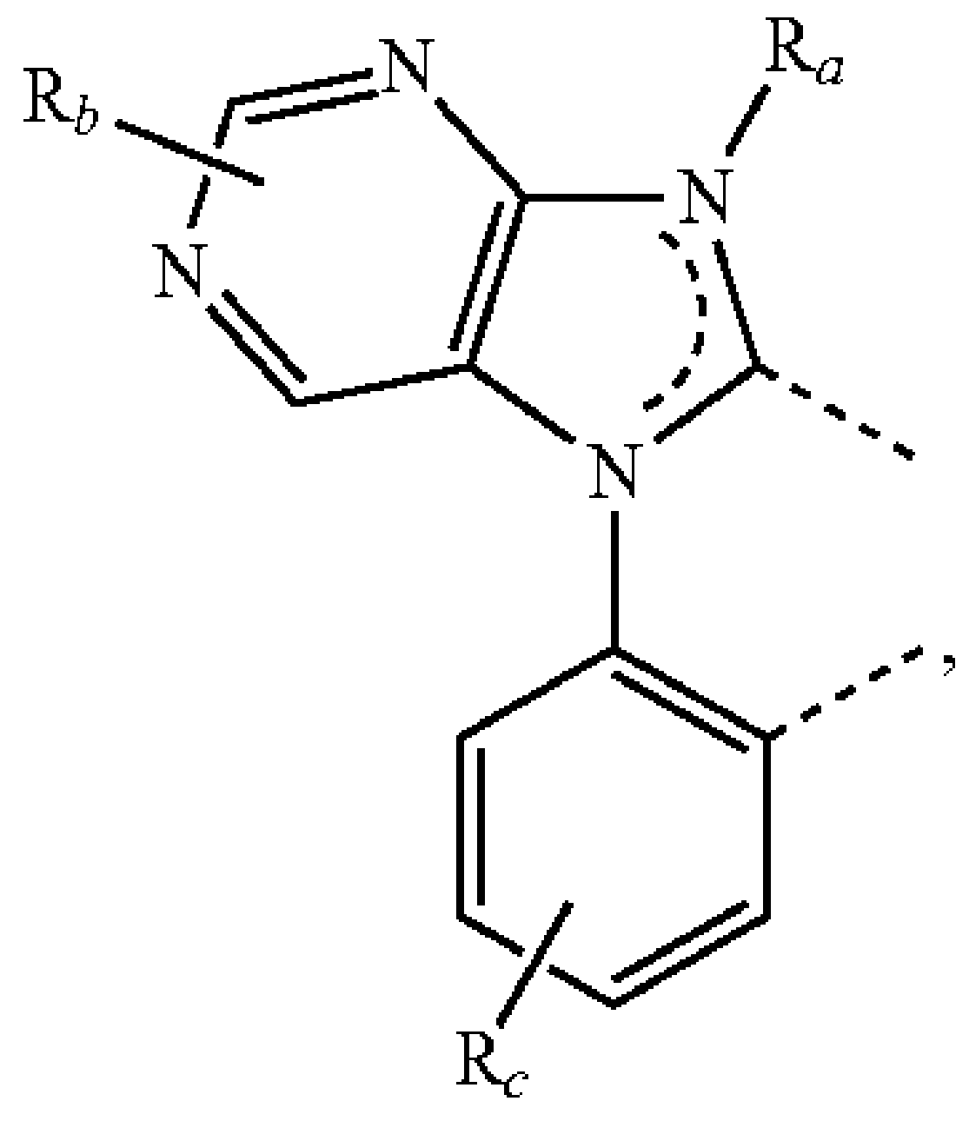






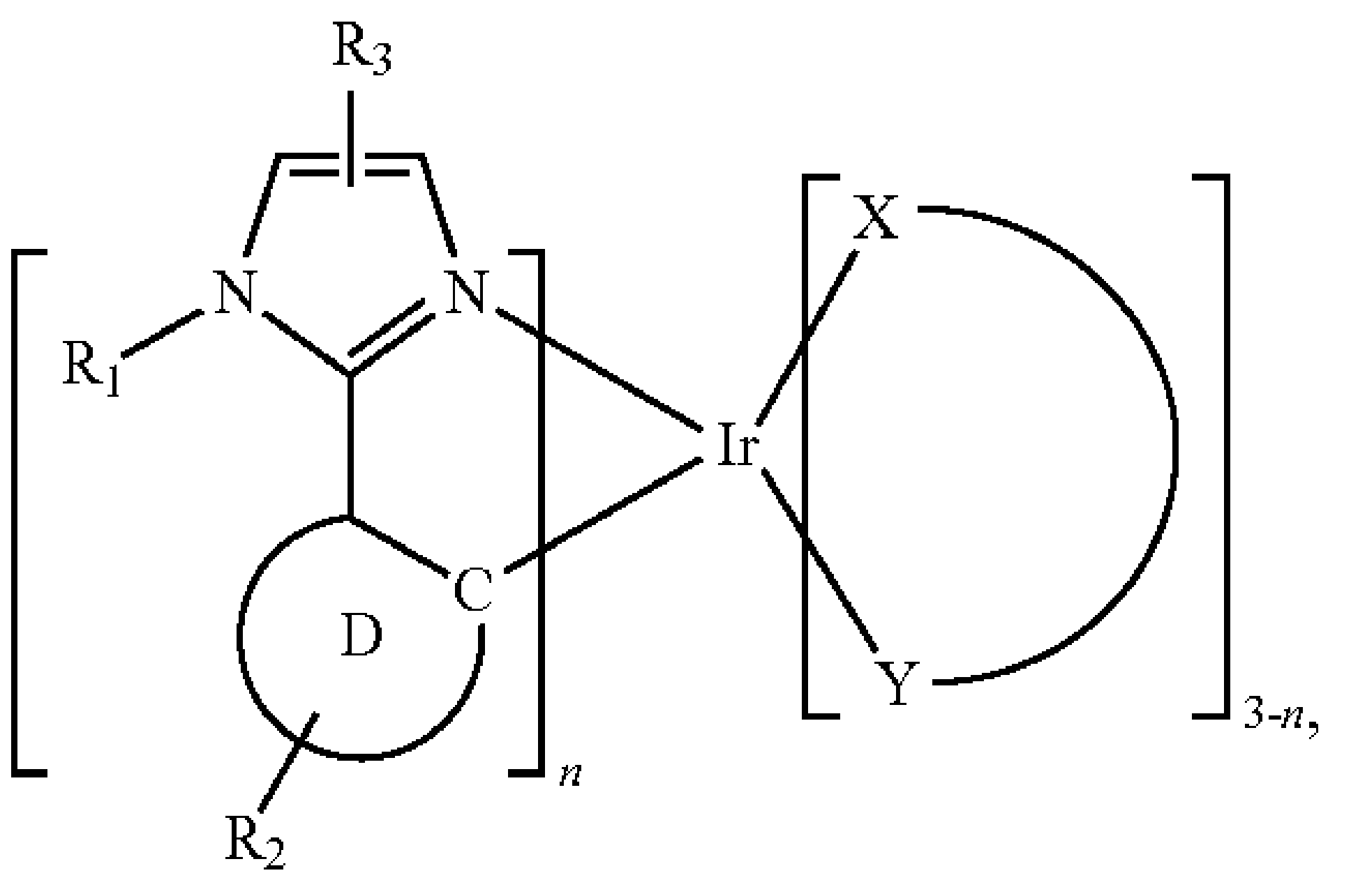






wherein R_a, R_b, and R_c may represent mono, di, tri or tetra substitutions, wherein R_a, R_b, and R_c are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and wherein two adjacent substituents of R_a, R_b, and R_c are optionally joined to form a fused ring.

In one embodiment, the emissive dopant has the formula



wherein D is a 5- or 6-membered carbocyclic or heterocyclic ring, wherein R_1, R_2, and R_3 independently represent mono, di, tri or tetra substitution, wherein each of R_1, R_2, and R_3 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, wherein R_1 can be optionally linked to ring D, wherein n is 1, 2, or 3, and wherein X—Y is another ligand.

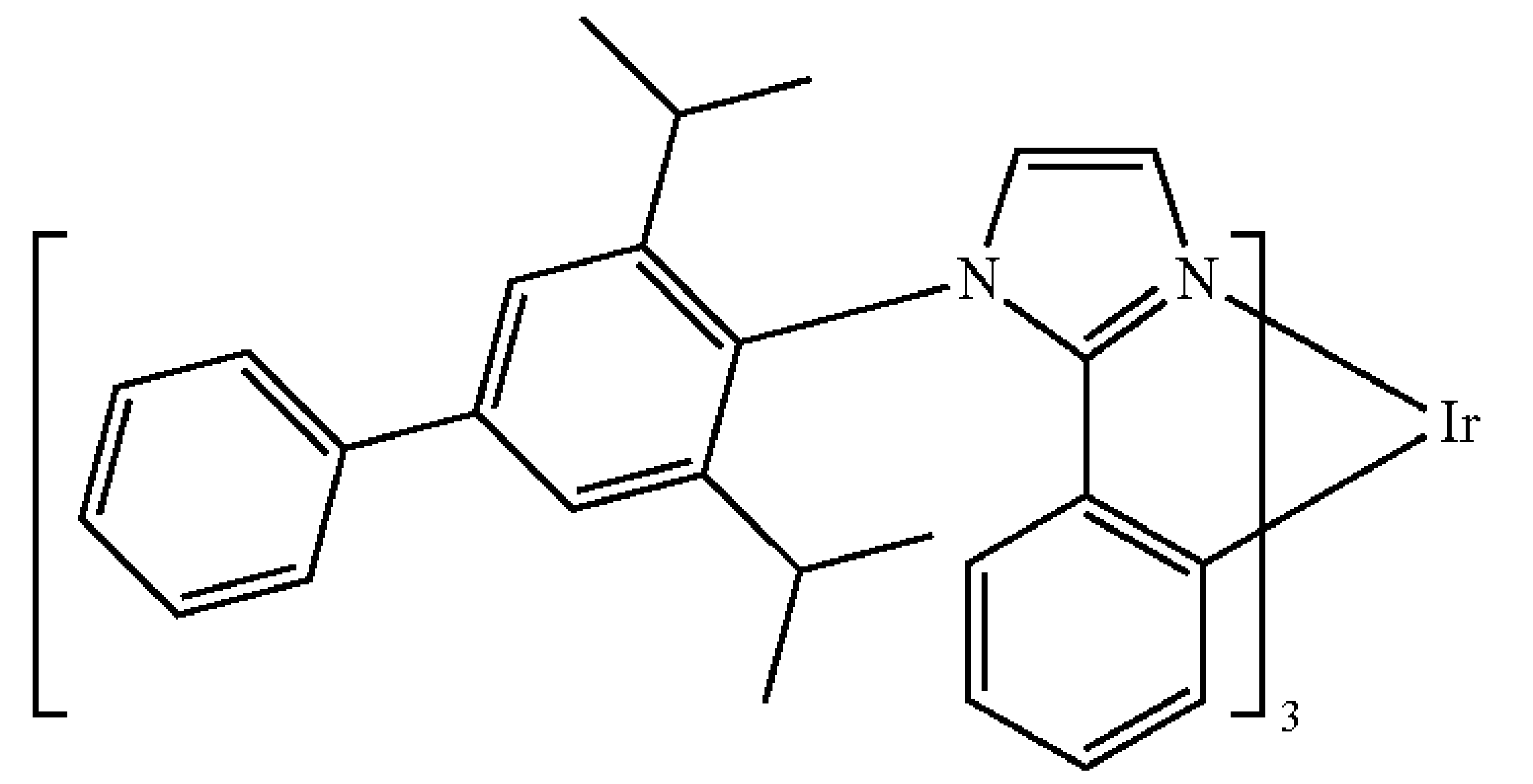
In one embodiment, the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer.

In another embodiment, the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer. In one embodiment, the second organic layer is an electron transporting layer and the compound having the Formula I is an electron transporting material in the second organic layer.

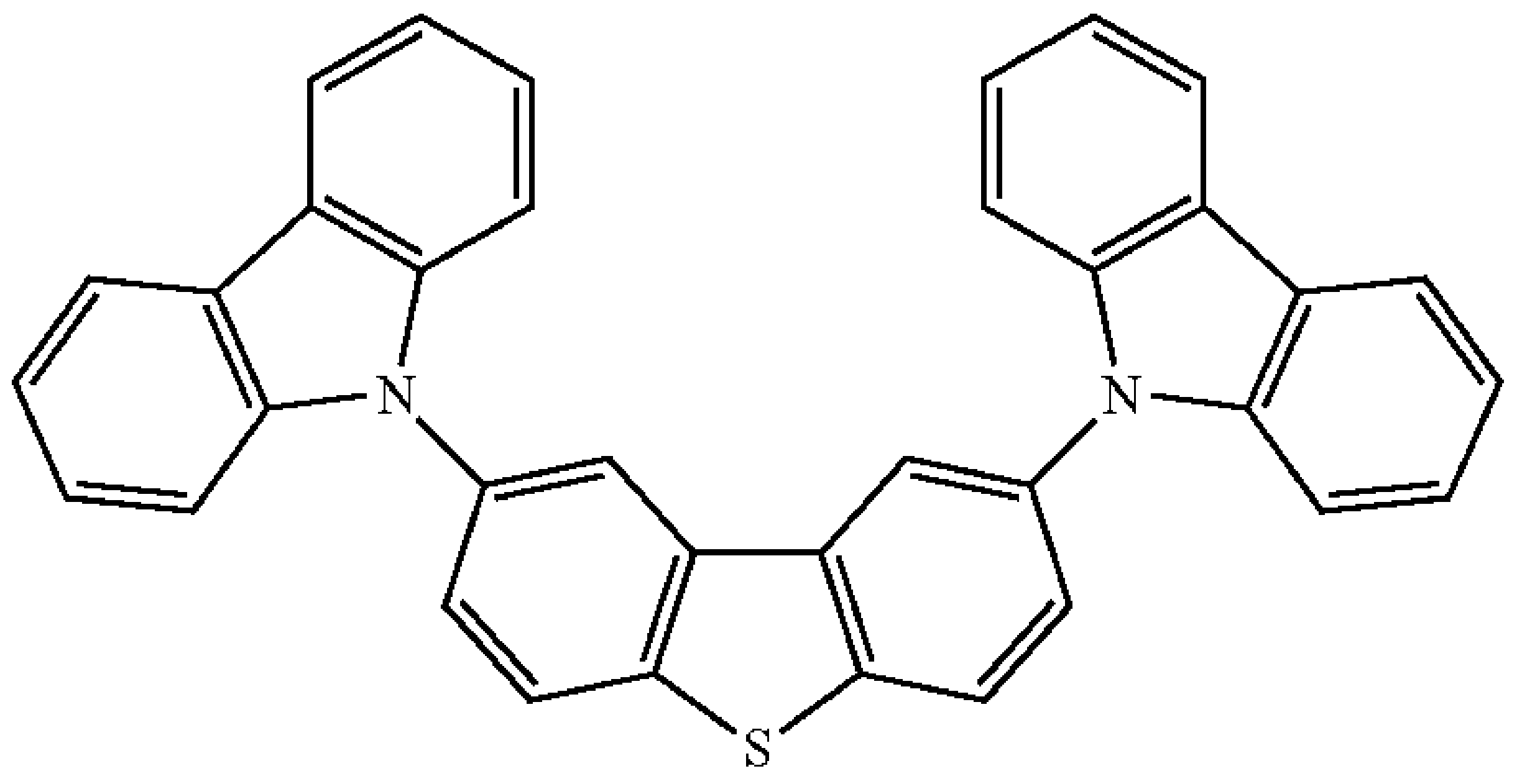
In one embodiment, the first device is a consumer product. In another embodiment, the first device is an organic light-emitting device. In one embodiment, the first device comprises a lighting panel.

Device Examples

The exemplary devices described below may advantageously utilize the compounds of Formula I, and are not intended to be limiting. The structures of the materials used in the device examples are shown below:



Dopant D



Compound BL

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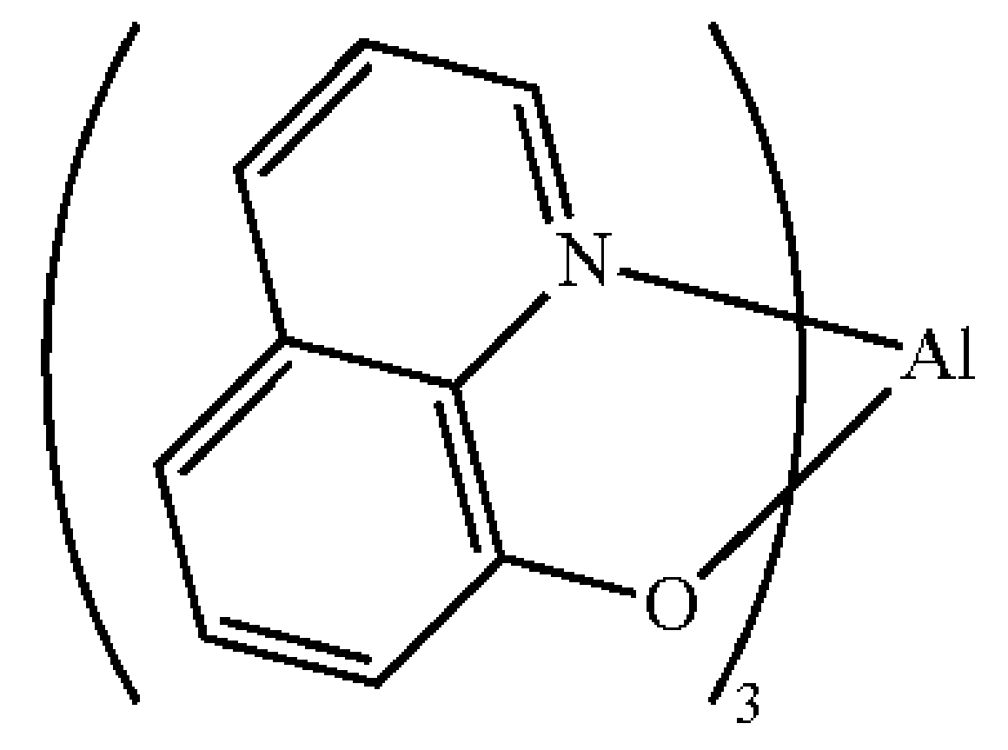
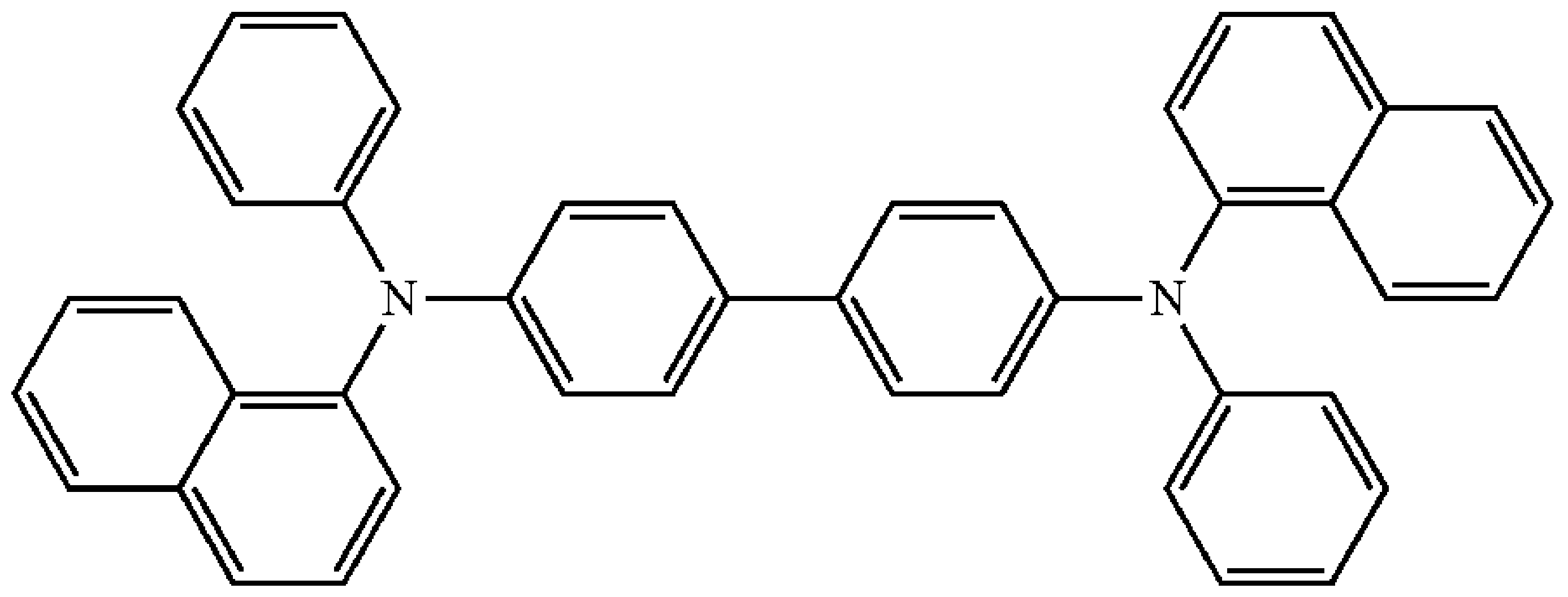


Alq



Compound NPD

All example devices were fabricated by high vacuum ($<10^{-4}$ Torr) thermal evaporation (VTE). The anode electrode is 800 Å of indium tin oxide (ITO). The cathode consisted of 10 Å of LiF followed by 1,000 Å of Al. All devices are encapsulated with a glass lid sealed with an epoxy resin in a nitrogen glove box (<1 ppm of H_2O and O_2) immediately after fabrication, and a moisture getter was incorporated inside the package.

The organic stack of the OLED device used in the Examples and Comparative Device Examples has the following structure: from the ITO surface, 100 Å of LG101 (purchased from LG Chem) as the hole injection layer, 300 Å of NPD as the hole transporting layer (HTL), 300 Å of a compound of Formula I (or comparative compound CC-1 or CC2) doped with 15 weight percent of Dopant D as the emissive layer (EML), 50 Å of Compound BL as the Blocking Layer (BL) and 400 Å of Alq as the electron transport layer (ETL). A schematic exemplary device structure is depicted in FIG. **4**.

TABLE 3

Summary of Device Data

							At 1000 nits			At
				1931 CIE		λ_{max}	LE	EQE	PE	20 mA/cm^2
Example	Host	Dopant	BL	x	y	[nm]	[cd/A]	[%]	[lm/W]	$LT_{80\%}$ [h]
Device Example 1	Compound 1	Dopant D	Compound BL	0.173	0.3913	474	44.7	19.8	24	11.4
Device Example2	Compound 3	Dopant D	Compound BL	0.1737	0.3887	474	44	19.5	23.4	16.0

TABLE 3-continued

Summary of Device Data

				1931 CIE		λ_{max}	At 1000 nits			At 20 mA/cm^2
Example	Host	Dopant	BL	x	y	[nm]	LE [cd/A]	EQE [%]	PE [lm/W]	$LT_{80\%}$ [h]
Device Example 3	Compound 4	Dopant D	Compound BL	0.1781	0.4034	476	44.3	19.2	22.9	24.2
Comparative Device Example 1	CC-1	Dopant D	Compound BL	0.1803	0.3877	474	23.7	10.5	10.3	18.5
Comparative Device Example 2	CC-2	Dopant D	Compound BL	0.1853	0.3986	474	24.3	10.5	9.8	0.01

Table 3 contains a summary of the device data. The luminous efficiency (LE), external quantum efficiency (EQE) and power efficiency (PE) were measured at 1000 nits, while the lifetime ($LT_{80\%}$) was defined as the time required for the device to decay to 80% of its initial luminance under a constant current density of 20 mA/cm^2. Compared to the devices based on comparative examples, i.e. Comparative Device Examples 1 and 2, the devices based on compounds of Formula I, i.e. Device Examples 1 to 3, exhibit two-fold improvement in device efficiencies (LE, EQE and PE), while maintaining comparable or even extended operational lifetimes. The improvement in device performance is attributable to the improved charge injection and transport of the asymmetric compounds of Formula I, which helps to balance charge fluxes. Without being bound by theory, it is believed that the balanced electron/hole fluxes spread the charge recombination zone, which preserves a high efficiency at high brightness by suppressing or reducing exciton quenching. An expanded charge recombination zone also extends the device lifetime by allowing a larger population of molecules to have charge transport, exciton formation, and light emission roles. Based on the HOMO/LUMO levels reported in Table 2, compounds of Formula I can also be used in the hole blocking layers. Since compounds of Formula I can serve both as hosts and hole blocking materials in the hole blocking layers, incorporation of compounds of Formula I into optical devices is expected to reduce device fabrication costs.

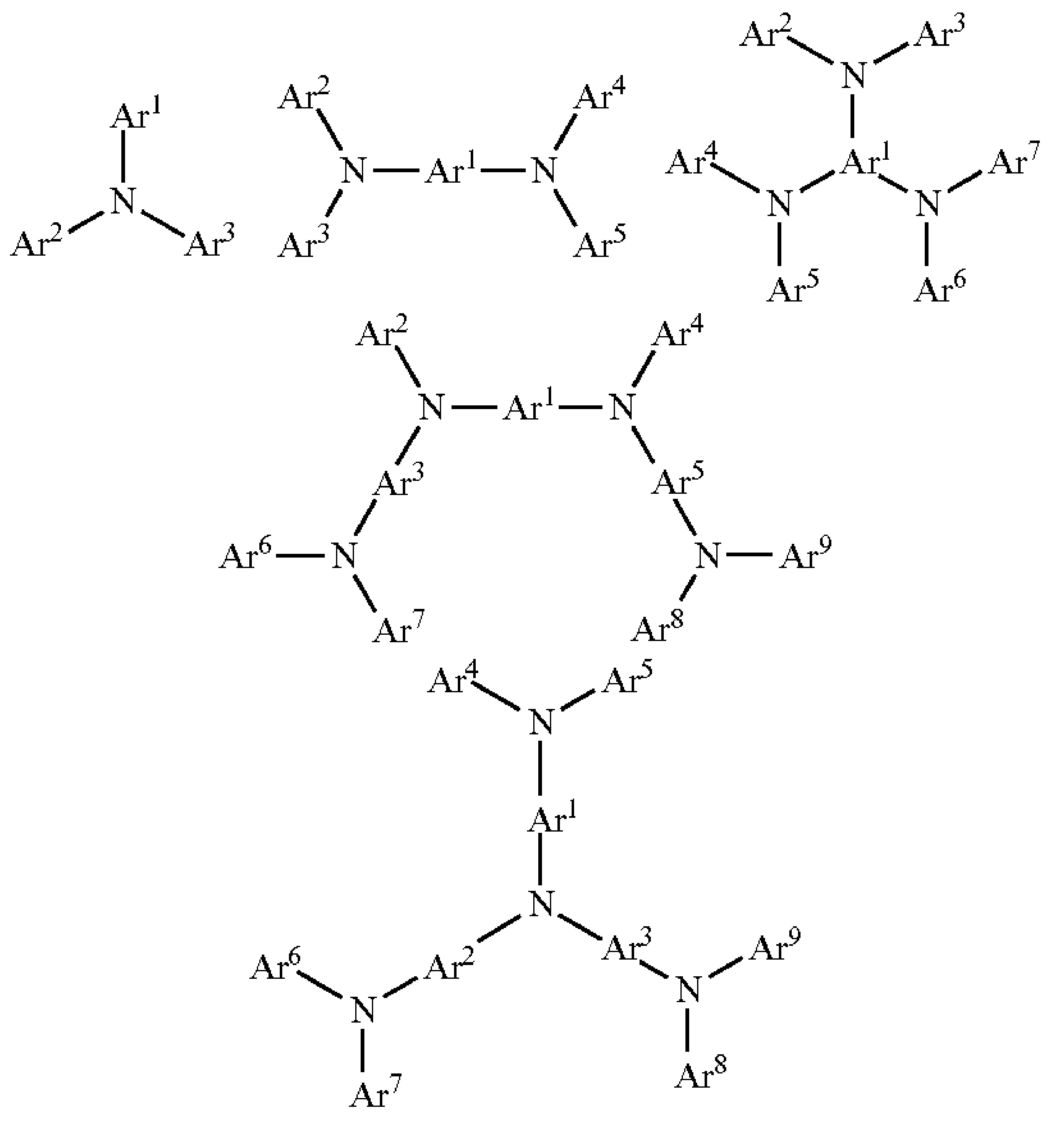
Combination with Other Materials

The materials described herein as useful for a particular layer in an organic light emitting device may be used in combination with a wide variety of other materials present in the device. For example, emissive dopants disclosed herein may be used in conjunction with a wide variety of hosts, transport layers, blocking layers, injection layers, electrodes and other layers that may be present. The materials described or referred to below are non-limiting examples of materials that may be useful in combination with the compounds disclosed herein, and one of skill in the art can readily consult the literature to identify other materials that may be useful in combination.

HIL/HTL:

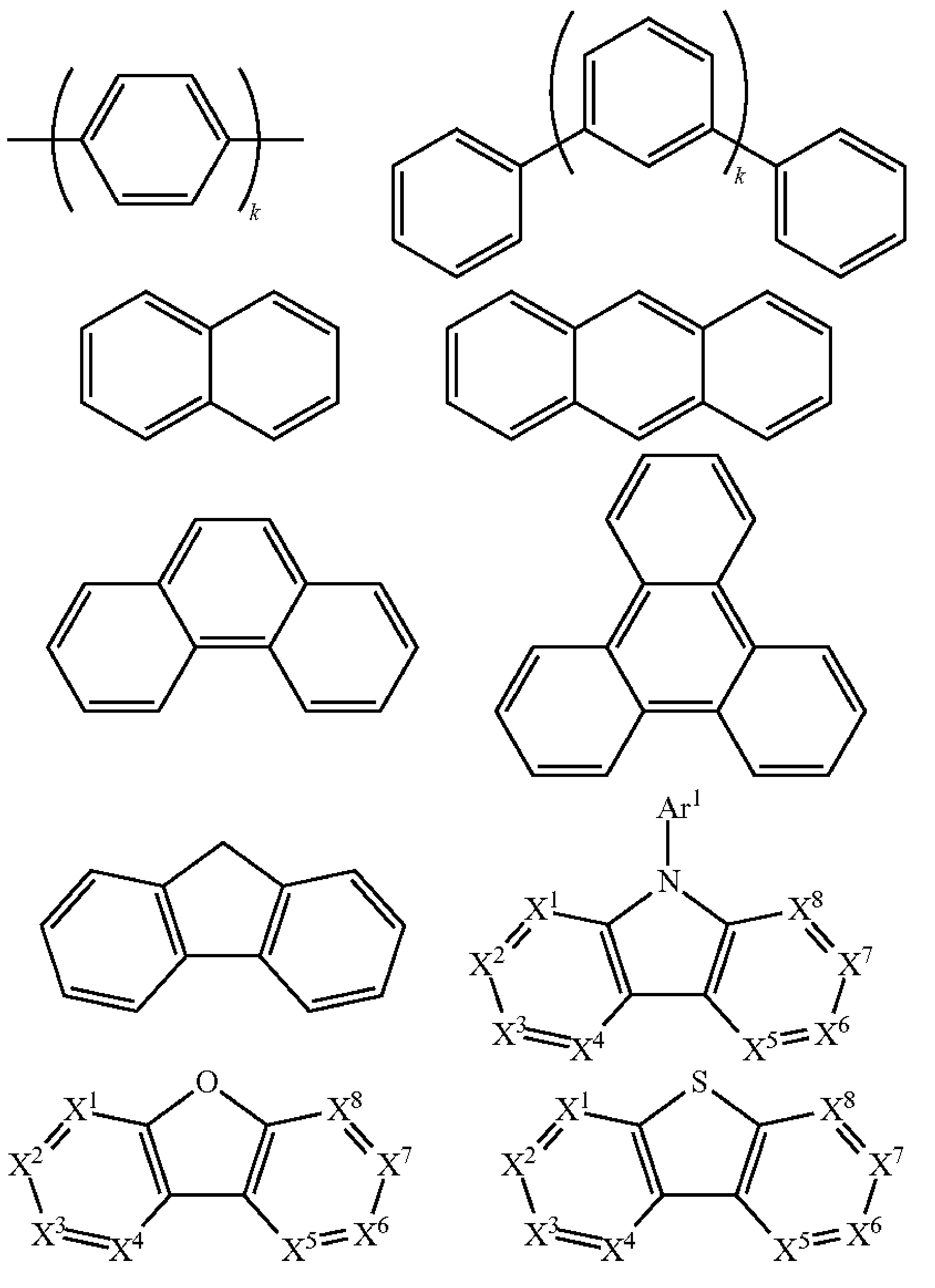
A hole injecting/transporting material to be used in the present invention is not particularly limited, and any compound may be used as long as the compound is typically used as a hole injecting/transporting material. Examples of the material include, but not limit to: a phthalocyanine or porphryin derivative; an aromatic amine derivative; an indolocarbazole derivative; a polymer containing fluorohydrocarbon; a polymer with conductivity dopants; a conducting polymer, such as PEDOT/PSS; a self-assembly monomer derived from compounds such as phosphonic acid and sliane derivatives; a metal oxide derivative, such as MoO_x; a p-type semiconducting organic compound, such as 1,4,5,8,9,12-Hexaazatriphenylenehexacarbonitrile; a metal complex, and a cross-linkable compounds.

Examples of aromatic amine derivatives used in HIL or HTL include, but not limit to the following general structures:



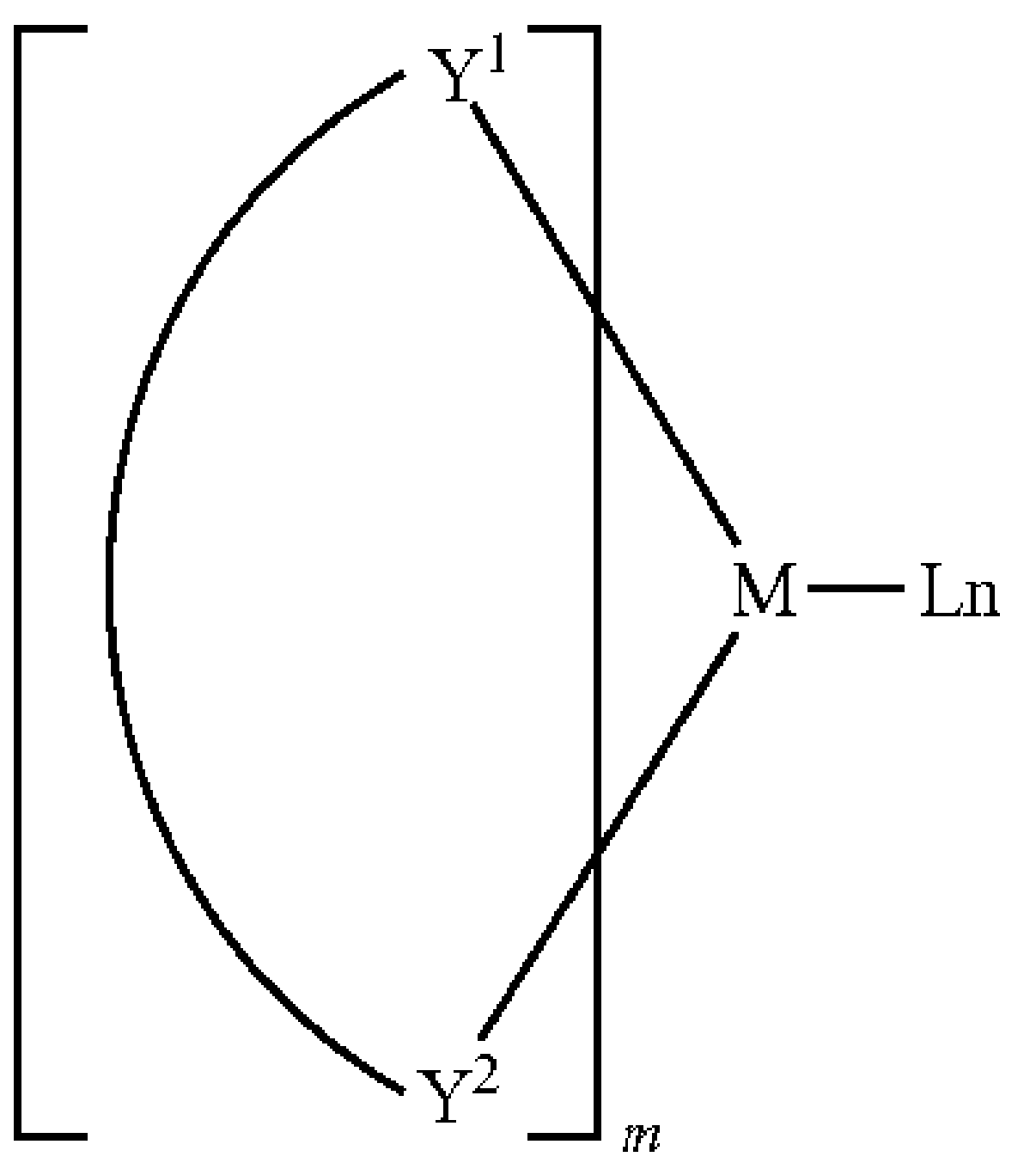
Each of Ar^1 to Ar^9 is selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each Ar is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

In one aspect, Ar^1 to Ar^9 is independently selected from the group consisting of:



k is an integer from 1 to 20; X^1 to X^8 is C (including CH) or N; Ar^1 has the same group defined above.

Examples of metal complexes used in HIL or HTL include, but not limit to the following general formula:



M is a metal, having an atomic weight greater than 40; (Y^1-Y^2) is a bidentate ligand, Y^1 and Y^2 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, (Y^1-Y^2) is a 2-phenylpyridine derivative.

In another aspect, (Y^1-Y^2) is a carbene ligand.

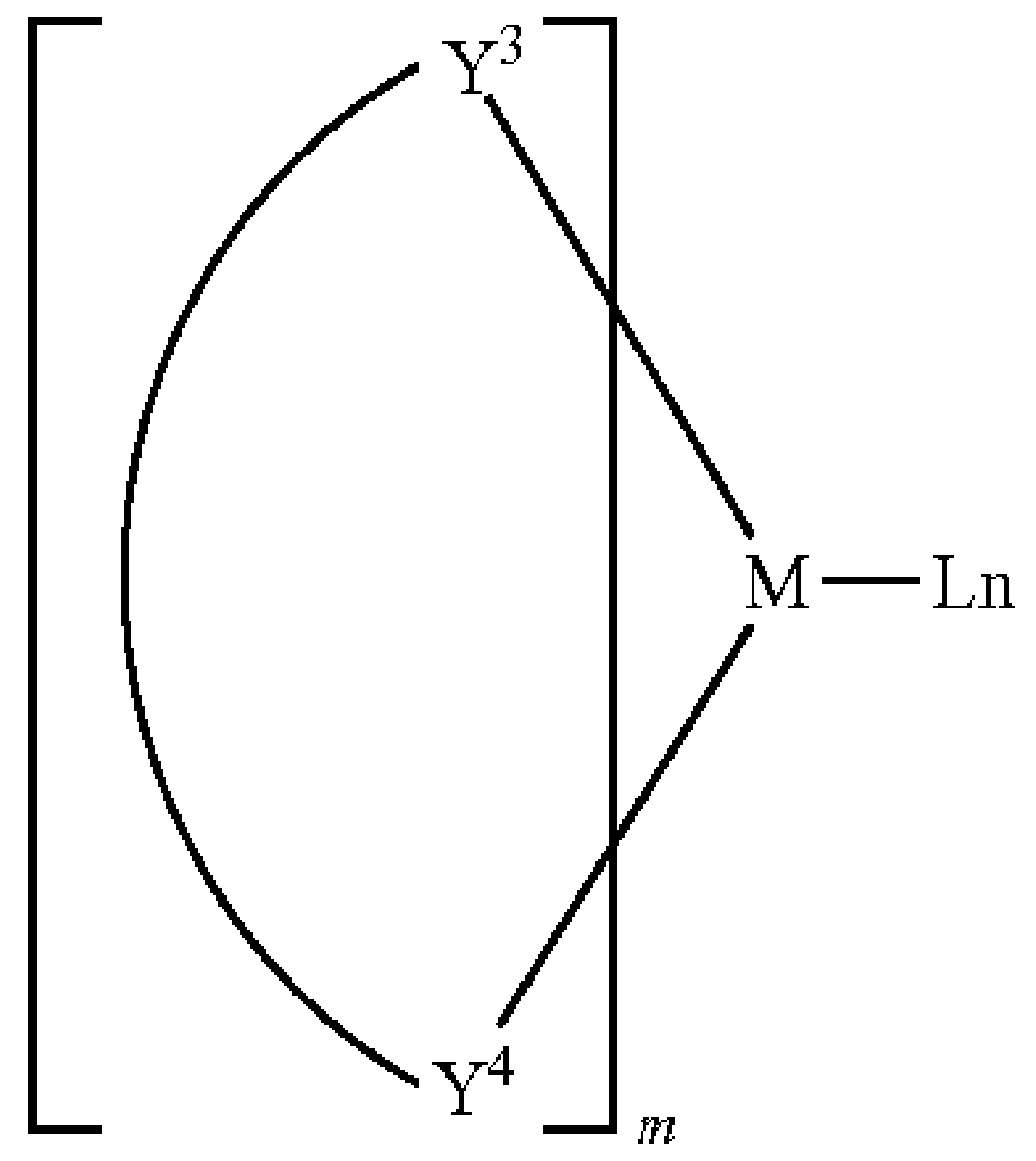
In another aspect, M is selected from Ir, Pt, Os, and Zn.

In a further aspect, the metal complex has a smallest oxidation potential in solution vs. Fc^+/Fc couple less than about 0.6 V.

Host:

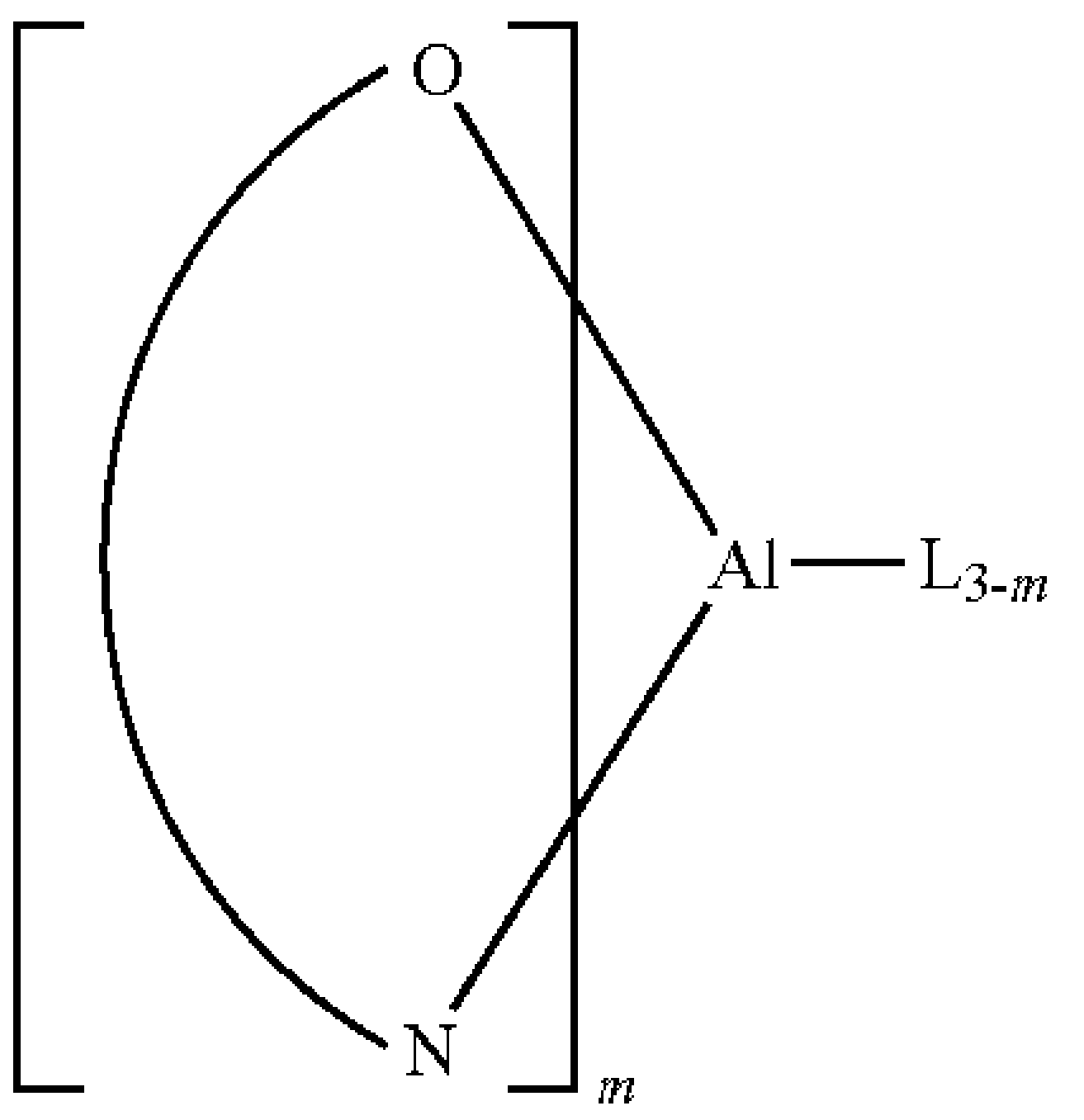
The light emitting layer of the organic EL device of the present invention preferably contains at least a metal complex as light emitting material, and may contain a host material using the metal complex as a dopant material. Examples of the host material are not particularly limited, and any metal complexes or organic compounds may be used as long as the triplet energy of the host is larger than that of the dopant. While the Table below categorizes host materials as preferred for devices that emit various colors, any host material may be used with any dopant so long as the triplet criteria is satisfied.

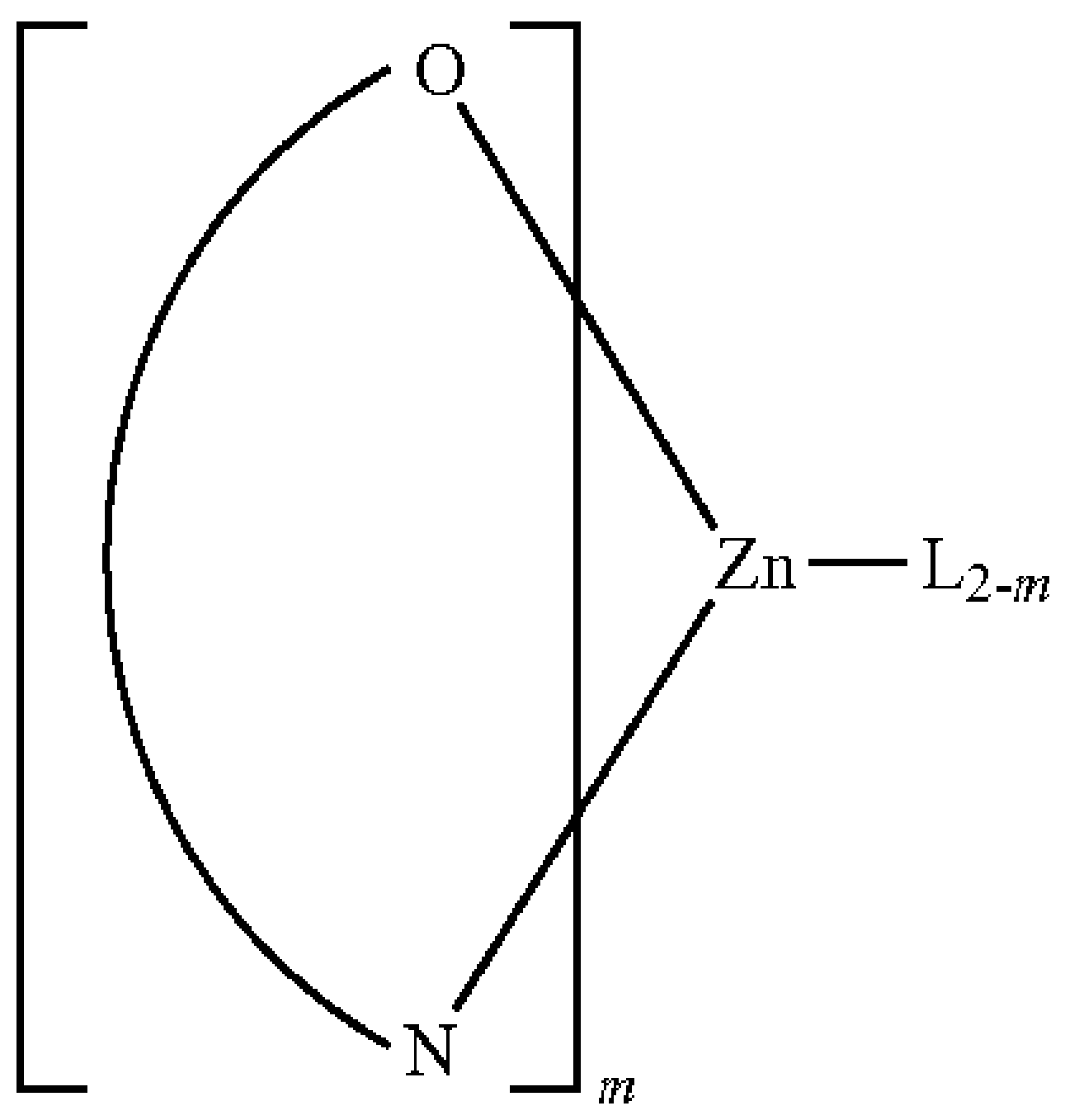
Examples of metal complexes used as host are preferred to have the following general formula:



M is a metal; (Y^3-Y^4) is a bidentate ligand, Y^3 and Y^4 are independently selected from C, N, O, P, and S; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal; and m+n is the maximum number of ligands that may be attached to the metal.

In one aspect, the metal complexes are:





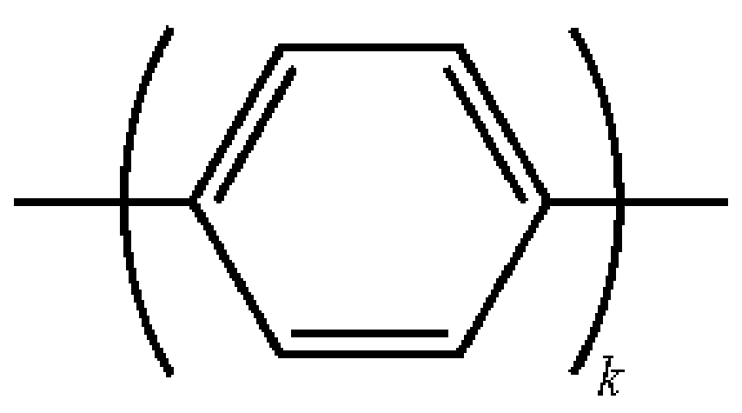
(O—N) is a bidentate ligand, having metal coordinated to atoms O and N.

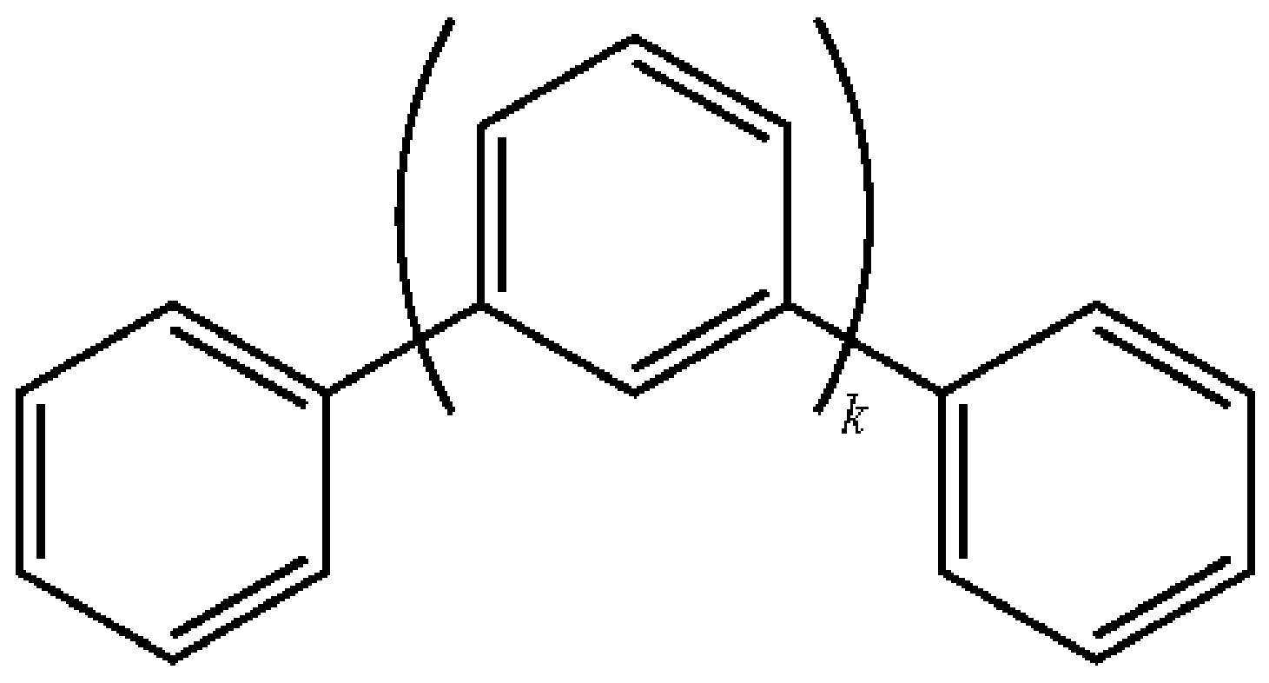
In another aspect, M is selected from Ir and Pt.

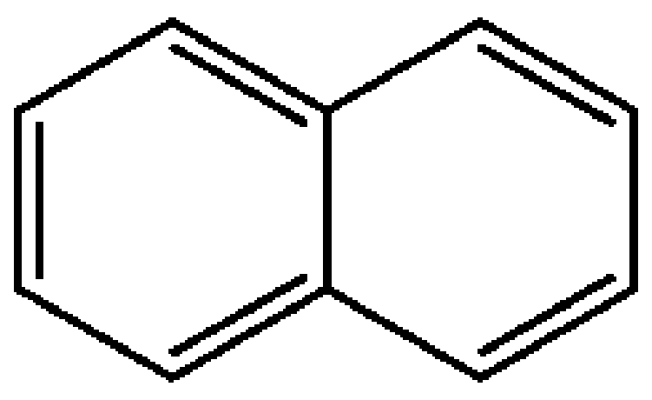
In a further aspect, (Y^3-Y^4) is a carbene ligand.

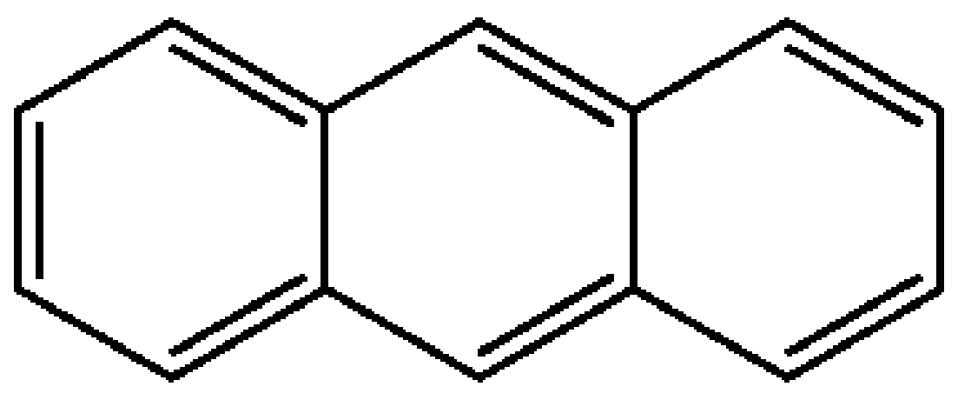
Examples of organic compounds used as host are selected from the group consisting aromatic hydrocarbon cyclic compounds such as benzene, biphenyl, triphenyl, triphenylene, naphthalene, anthracene, phenalene, phenanthrene, fluorene, pyrene, chrysene, perylene, azulene; group consisting aromatic heterocyclic compounds such as dibenzothiophene, dibenzofuran, dibenzoselenophene, furan, thiophene, benzofuran, benzothiophene, benzoselenophene, carbazole, indolocarbazole, pyridylindole, pyrrolodipyridine, pyrazole, imidazole, triazole, oxazole, thiazole, oxadiazole, oxatriazole, dioxazole, thiadiazole, pyridine, pyridazine, pyrimidine, pyrazine, triazine, oxazine, oxathiazine, oxadiazine, indole, benzimidazole, indazole, indoxazine, benzoxazole, benzisoxazole, benzothiazole, quinoline, isoquinoline, cinnoline, quinazoline, quinoxaline, naphthyridine, phthalazine, pteridine, xanthene, acridine, phenazine, phenothiazine, phenoxazine, benzofuropyridine, furodipyridine, benzothienopyridine, thienodipyridine, benzoselenophenopyridine, and selenophenodipyridine; and group consisting 2 to 10 cyclic structural units which are groups of the same type or different types selected from the aromatic hydrocarbon cyclic group and the aromatic heterocyclic group and are bonded to each other directly or via at least one of oxygen atom, nitrogen atom, sulfur atom, silicon atom, phosphorus atom, boron atom, chain structural unit and the aliphatic cyclic group. Wherein each group is further substituted by a substituent selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

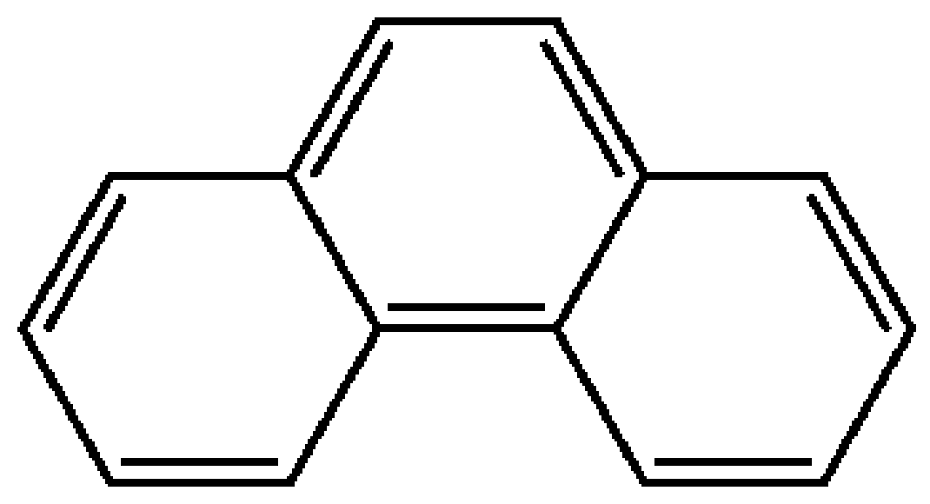
In one aspect, host compound contains at least one of the following groups in the molecule:

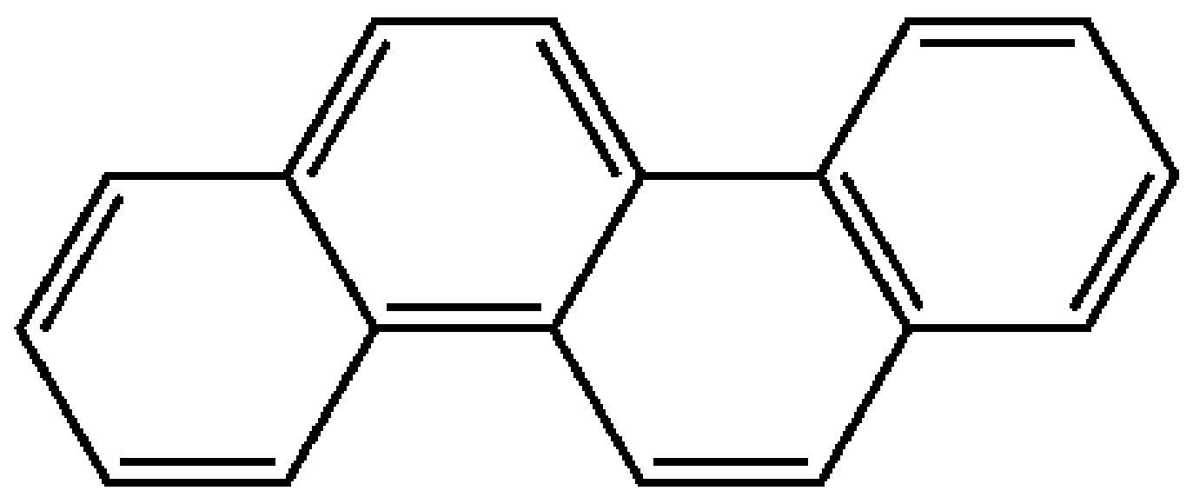


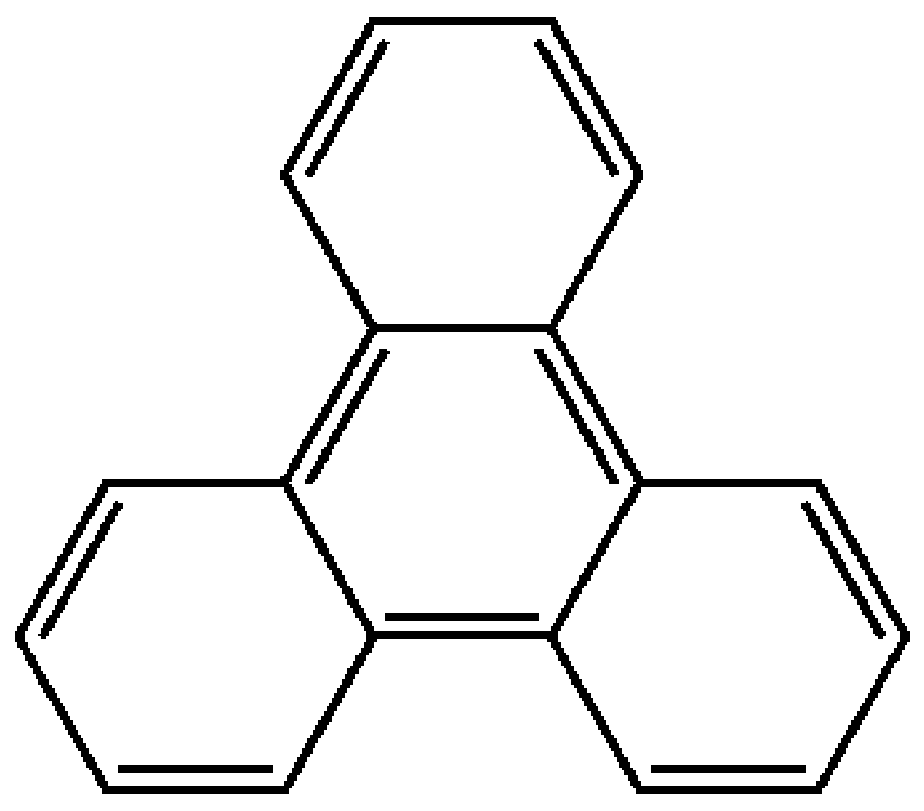


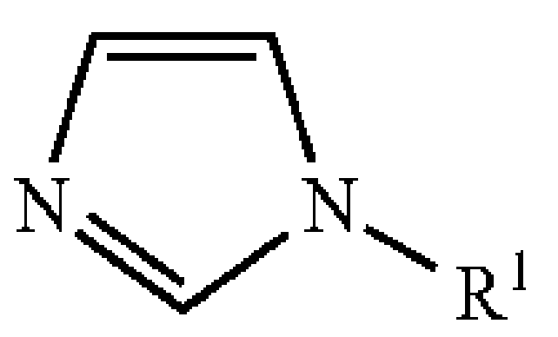


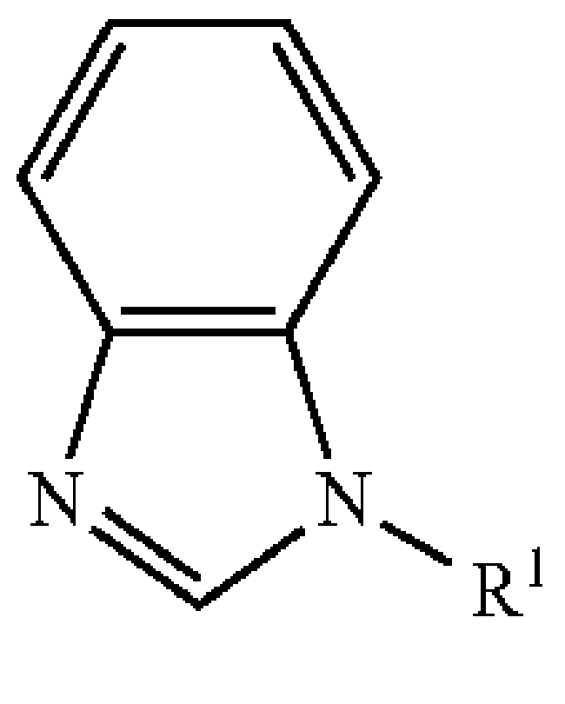


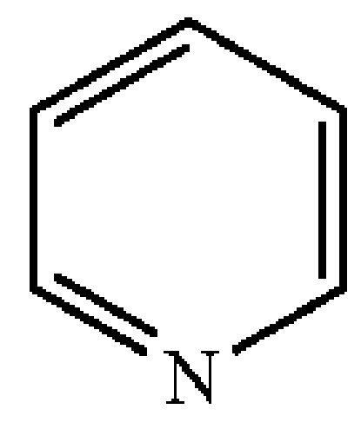


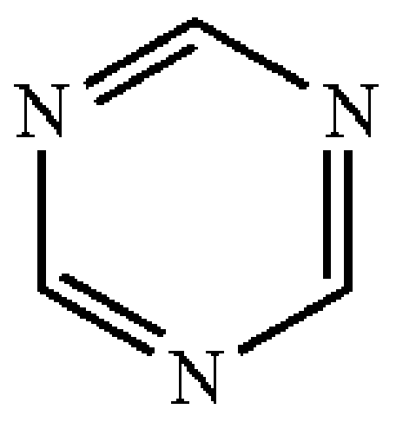


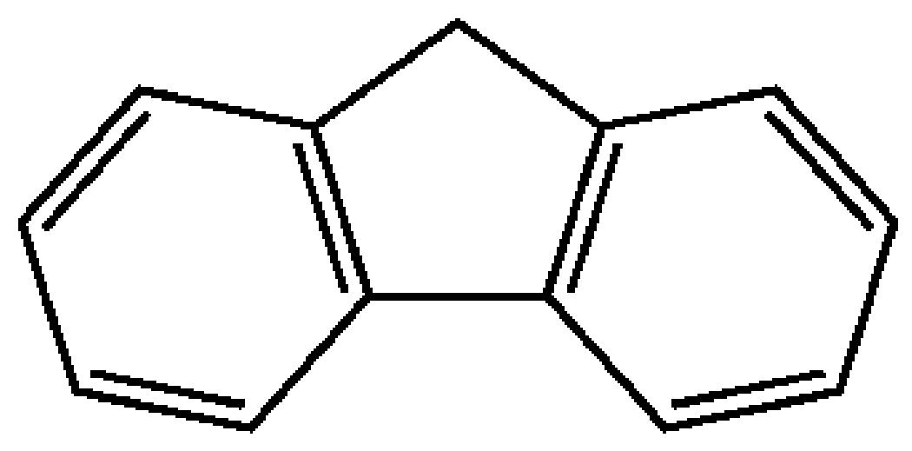


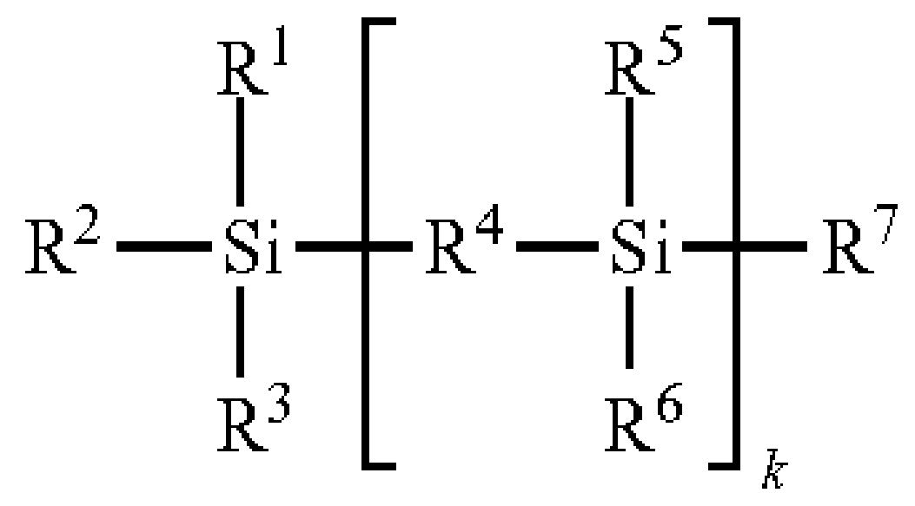












$$R^2-\underset{R^3}{\overset{R^1}{Si}}-\left[R^4-\underset{R^6}{\overset{R^5}{Si}}\right]_k-R^7$$

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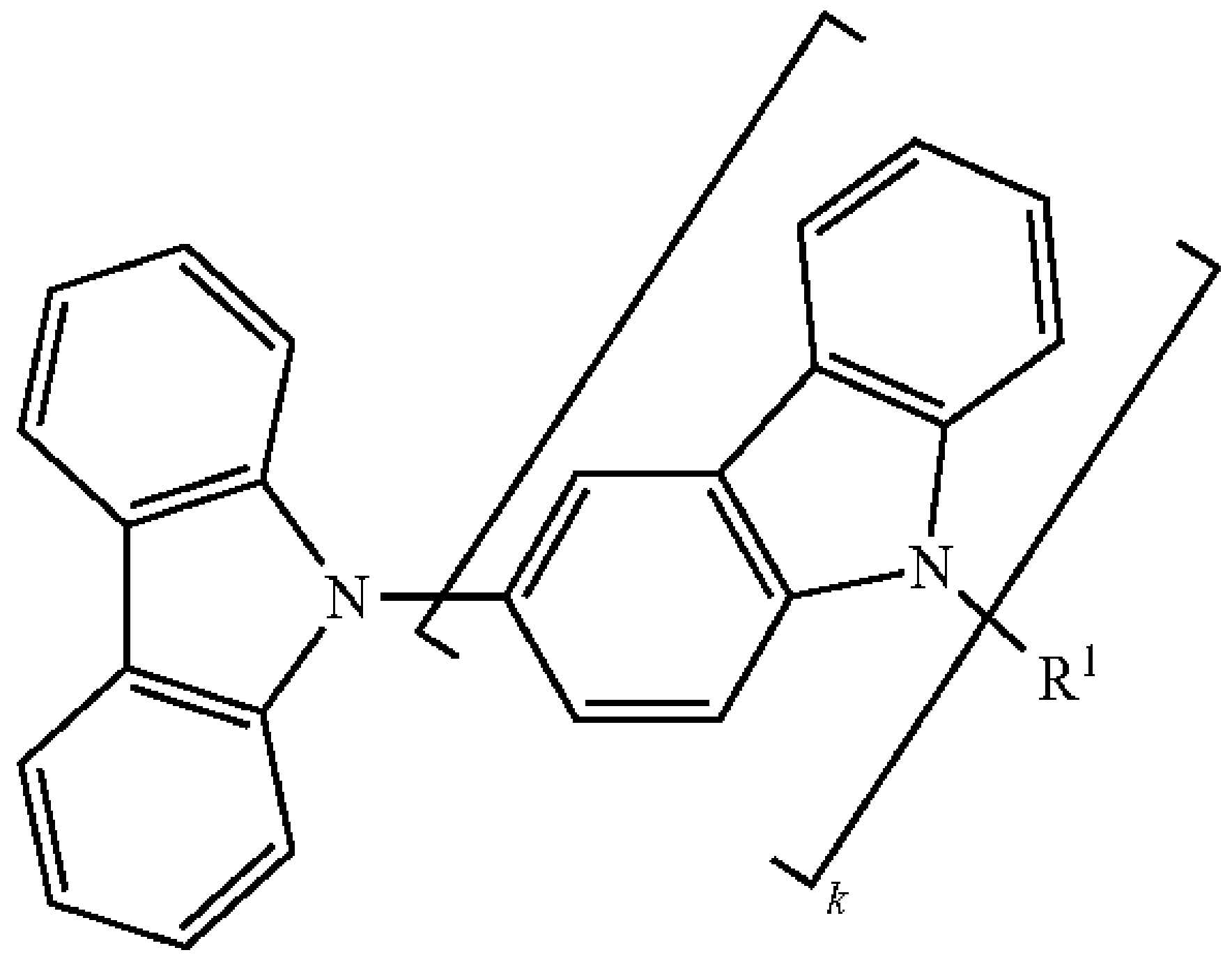
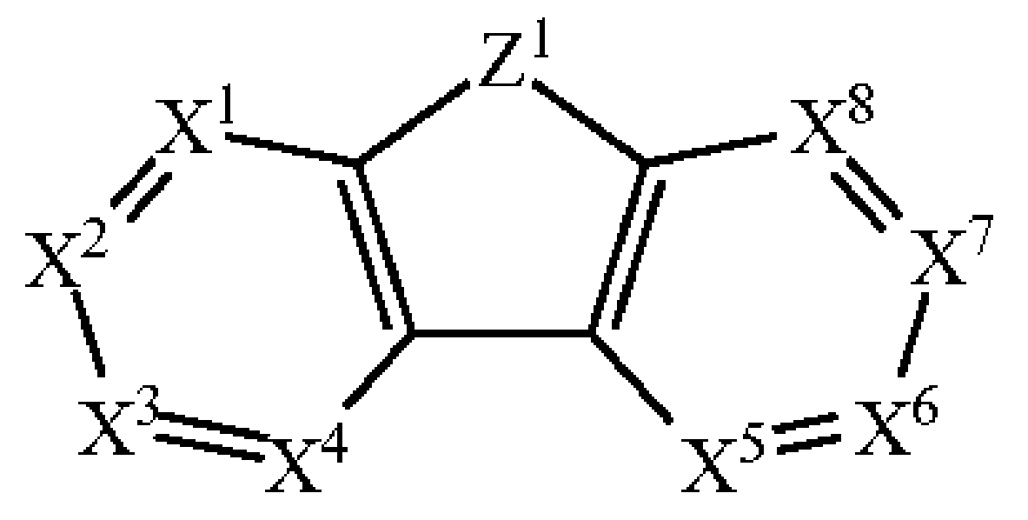
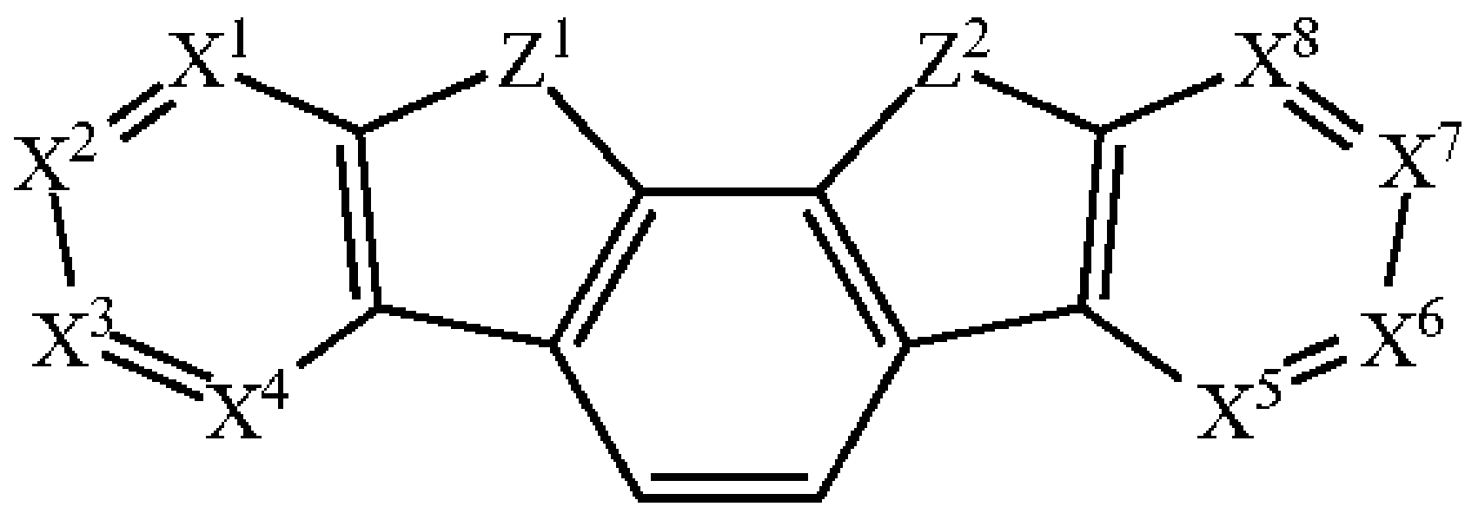
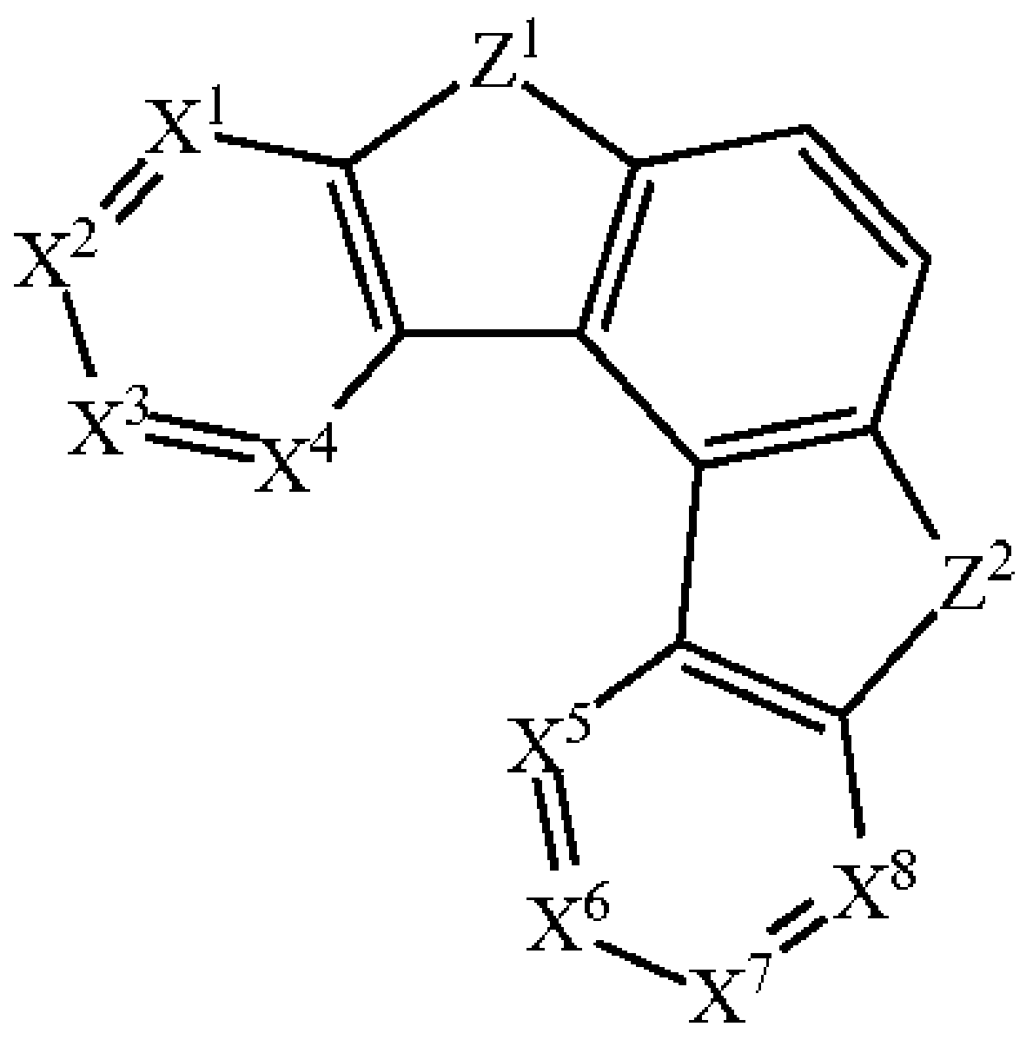
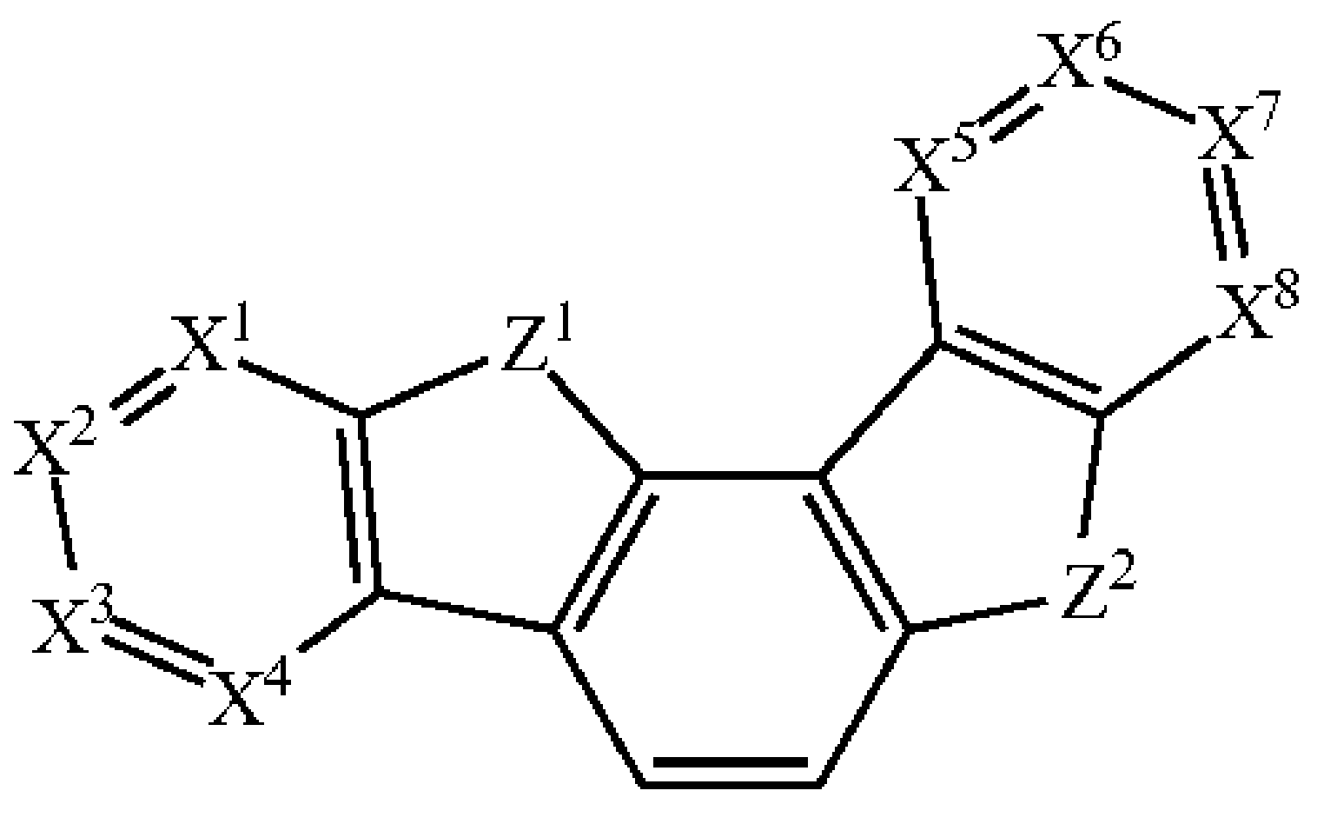
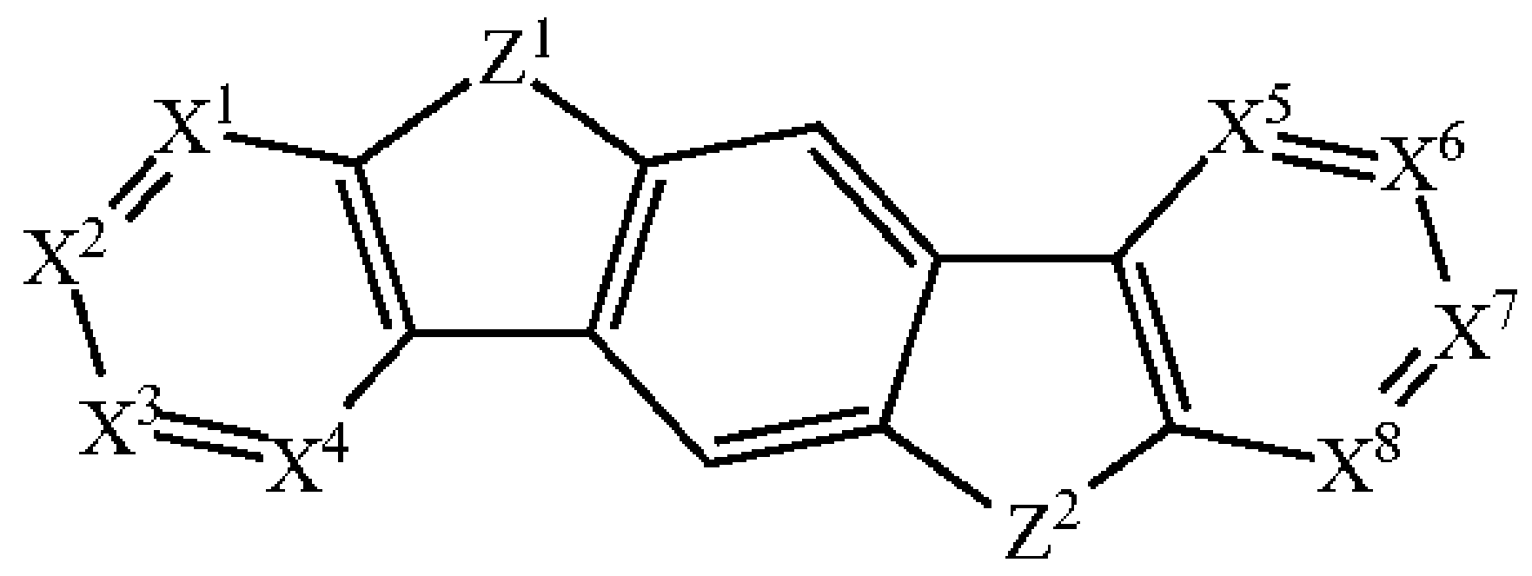


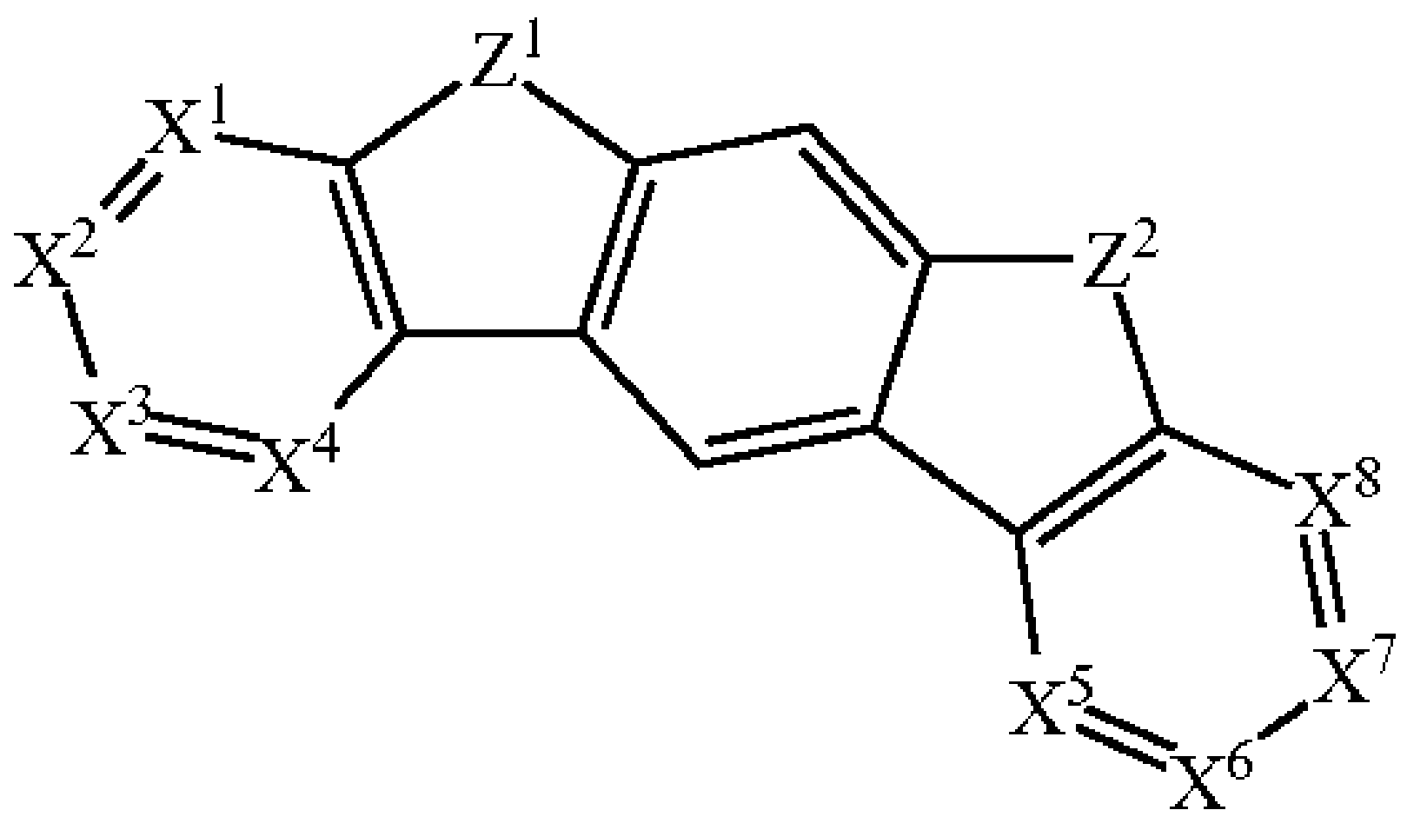












R^1 to R^7 is independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

k is an integer from 0 to 20.

X^1 to X^8 is selected from C (including CH) or N.

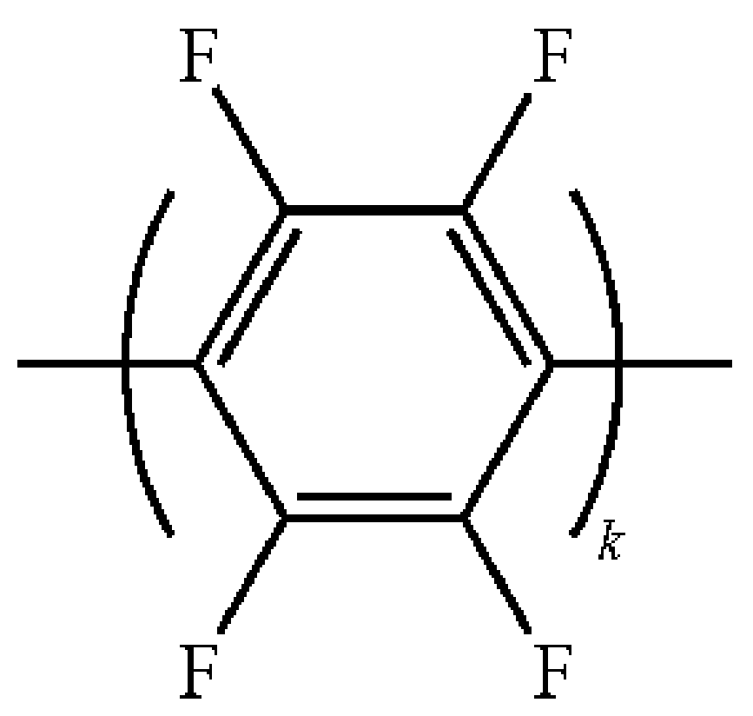
Z^1 and Z^2 is selected from NR^1, O, or S.

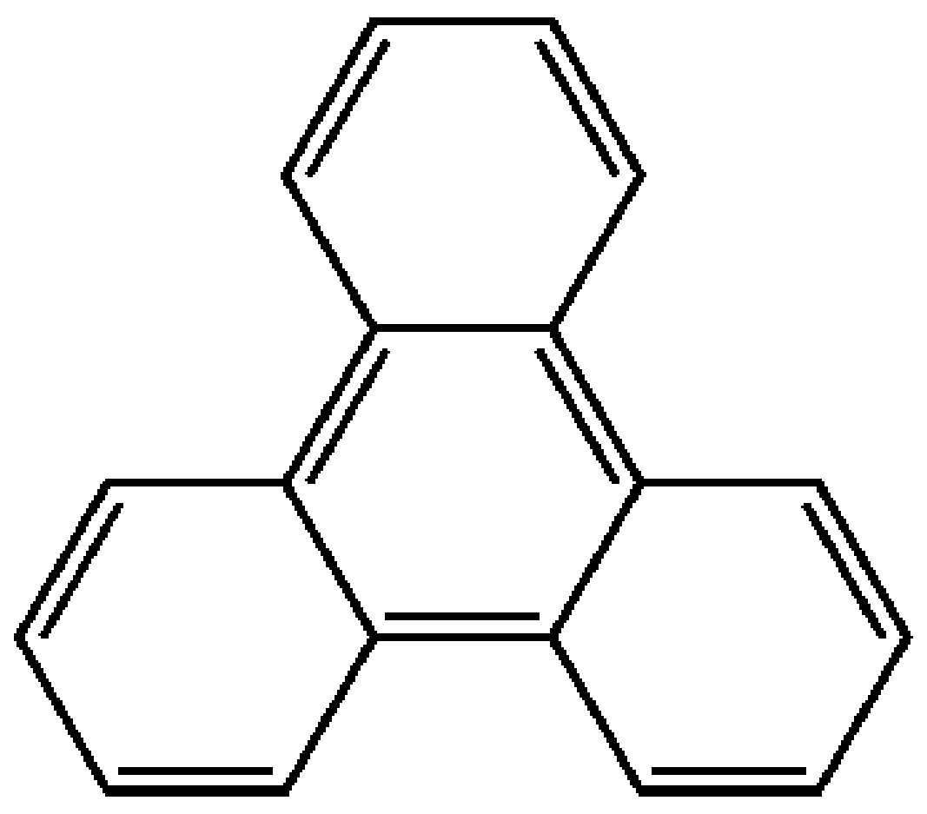
HBL:

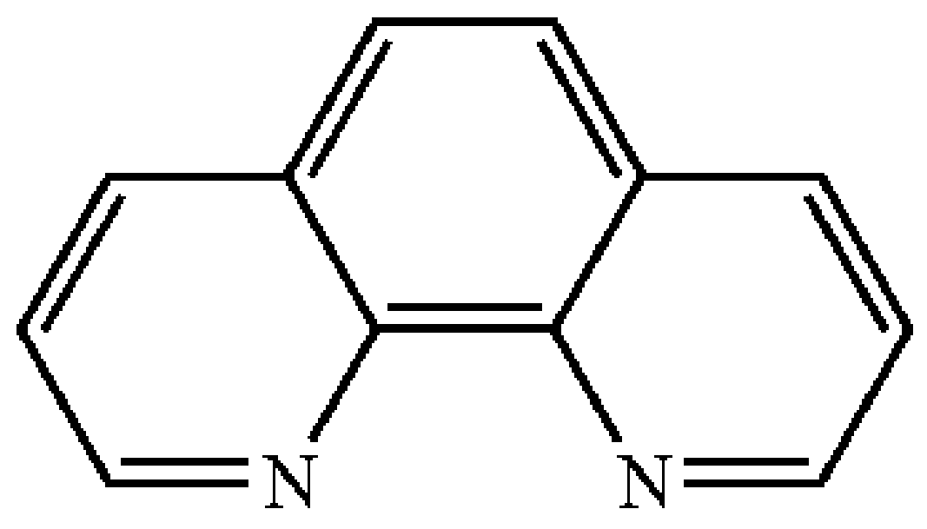
A hole blocking layer (HBL) may be used to reduce the number of holes and/or excitons that leave the emissive layer. The presence of such a blocking layer in a device may result in substantially higher efficiencies as compared to a similar device lacking a blocking layer. Also, a blocking layer may be used to confine emission to a desired region of an OLED.

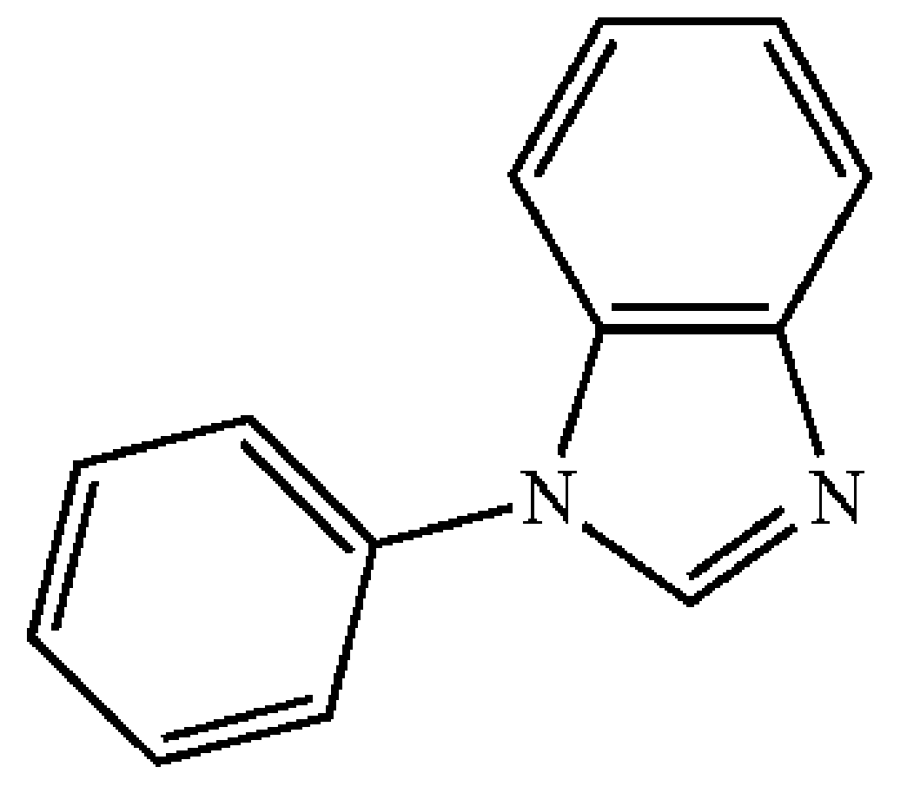
In one aspect, compound used in HBL contains the same molecule or the same functional groups used as host described above.

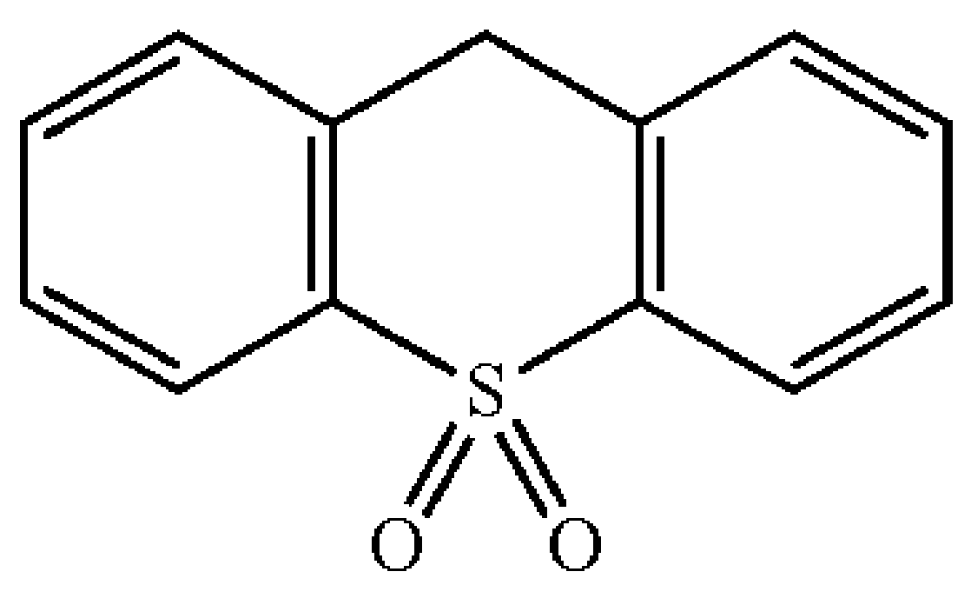
In another aspect, compound used in HBL contains at least one of the following groups in the molecule:

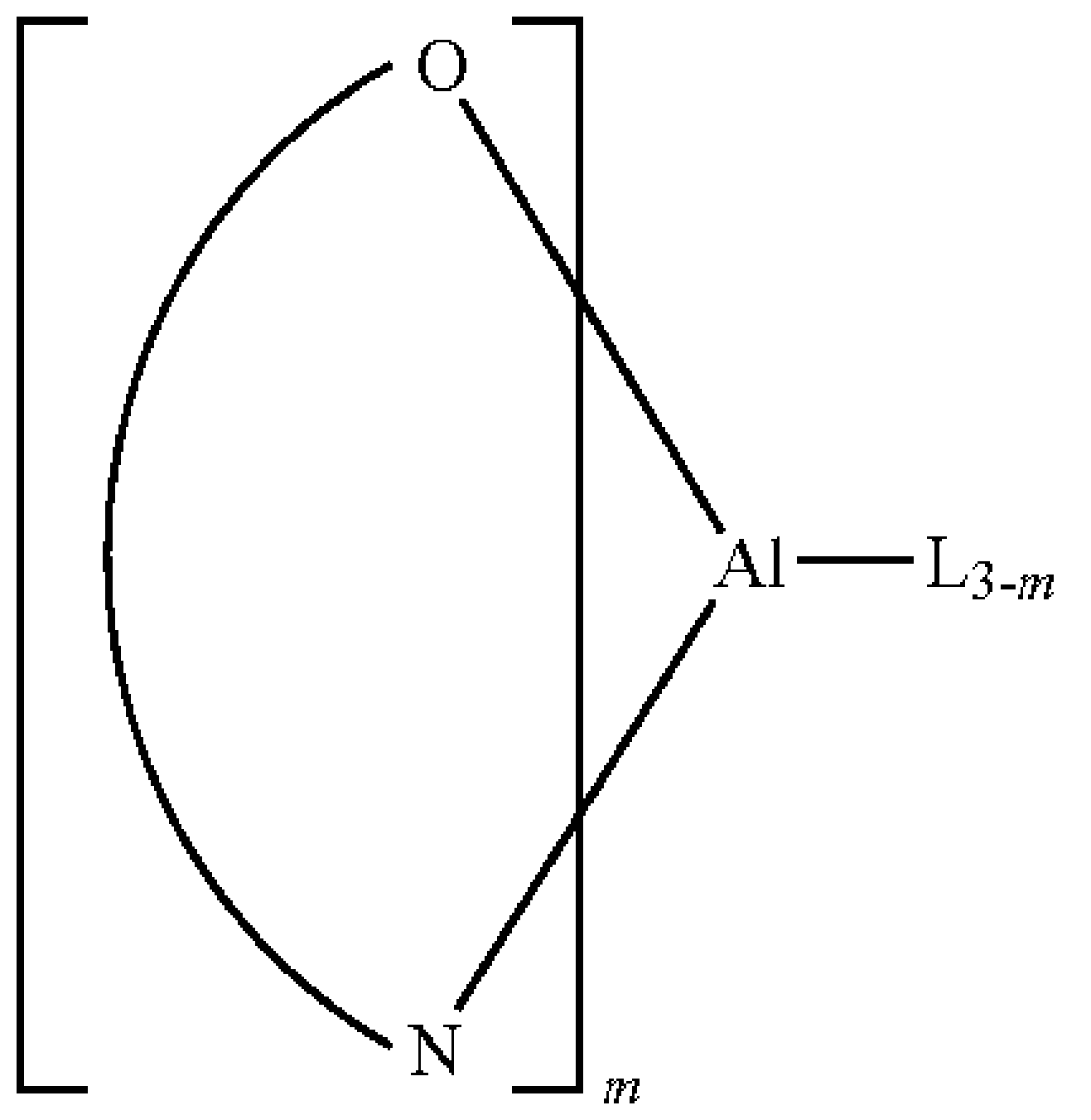










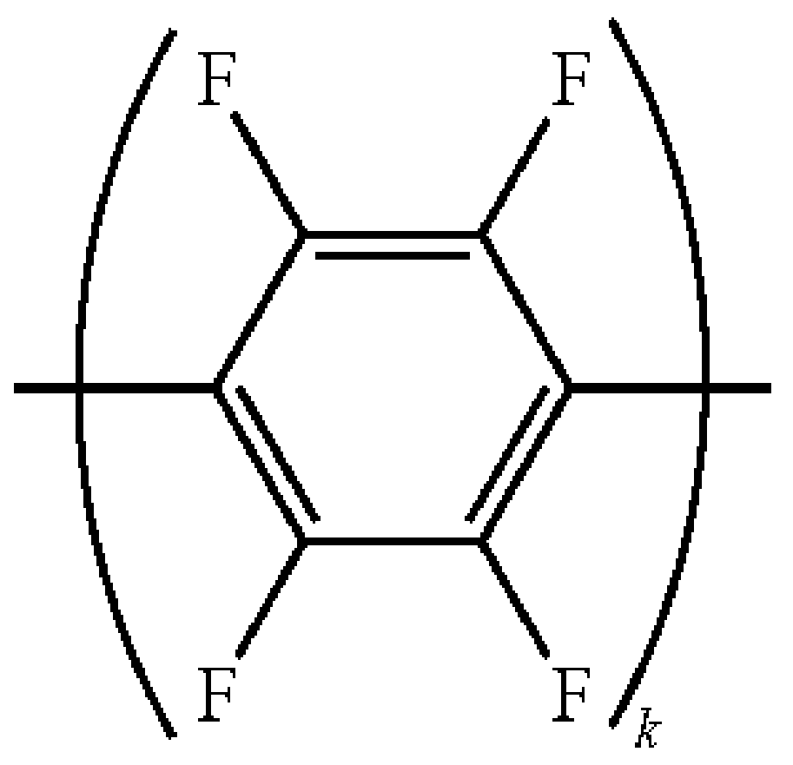


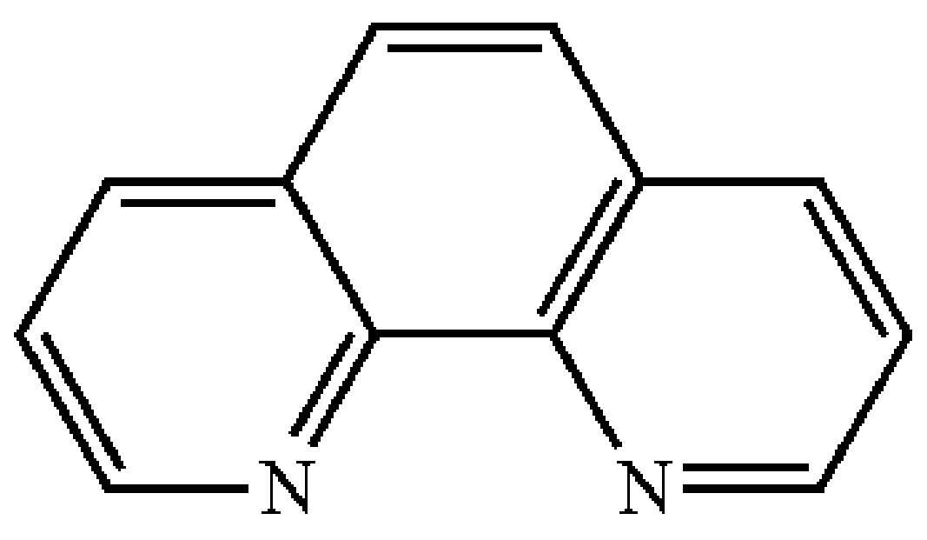
k is an integer from 0 to 20; L is an ancillary ligand, m is an integer from 1 to 3.

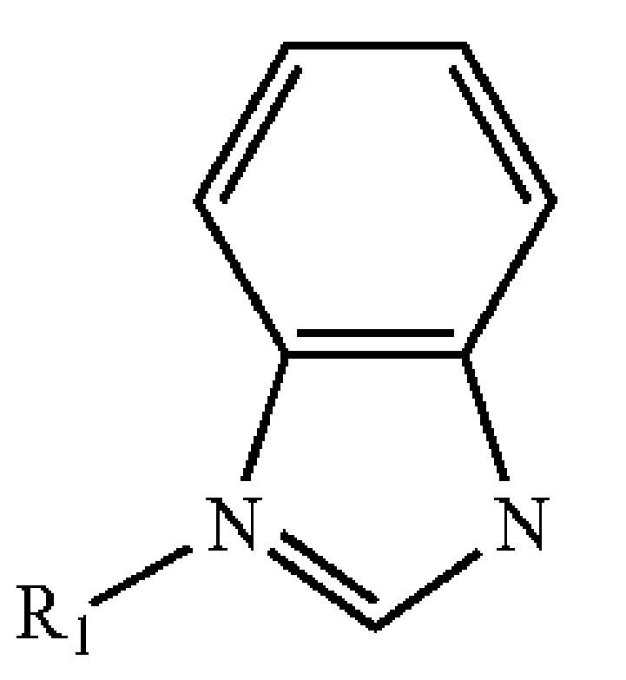
ETL:

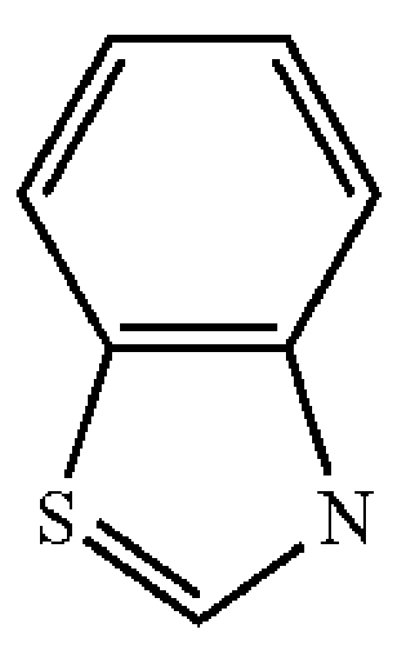
Electron transport layer (ETL) may include a material capable of transporting electrons. Electron transport layer may be intrinsic (undoped), or doped. Doping may be used to enhance conductivity. Examples of the ETL material are not particularly limited, and any metal complexes or organic compounds may be used as long as they are typically used to transport electrons.

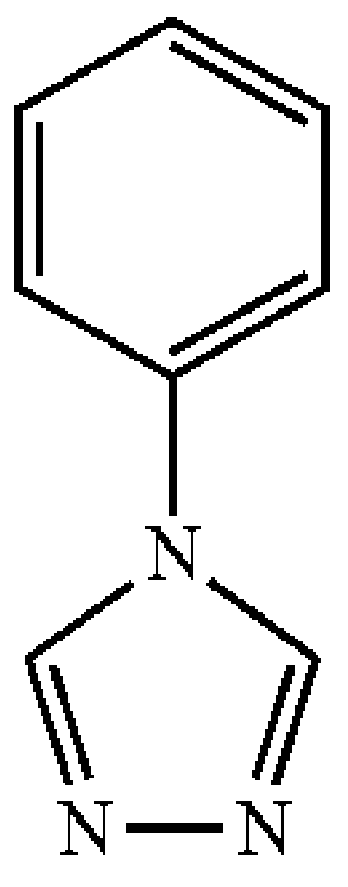
In one aspect, compound used in ETL contains at least one of the following groups in the molecule:

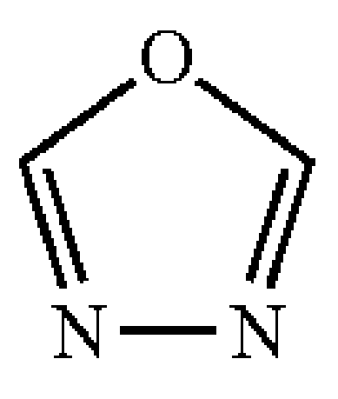












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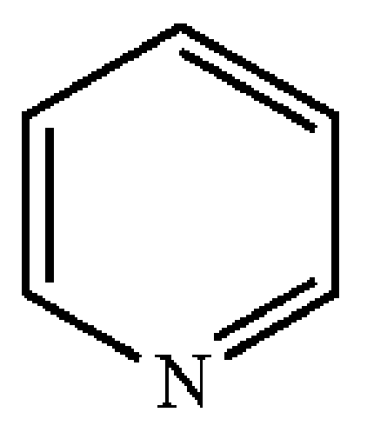
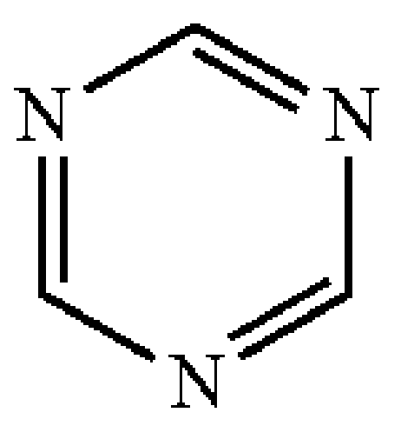
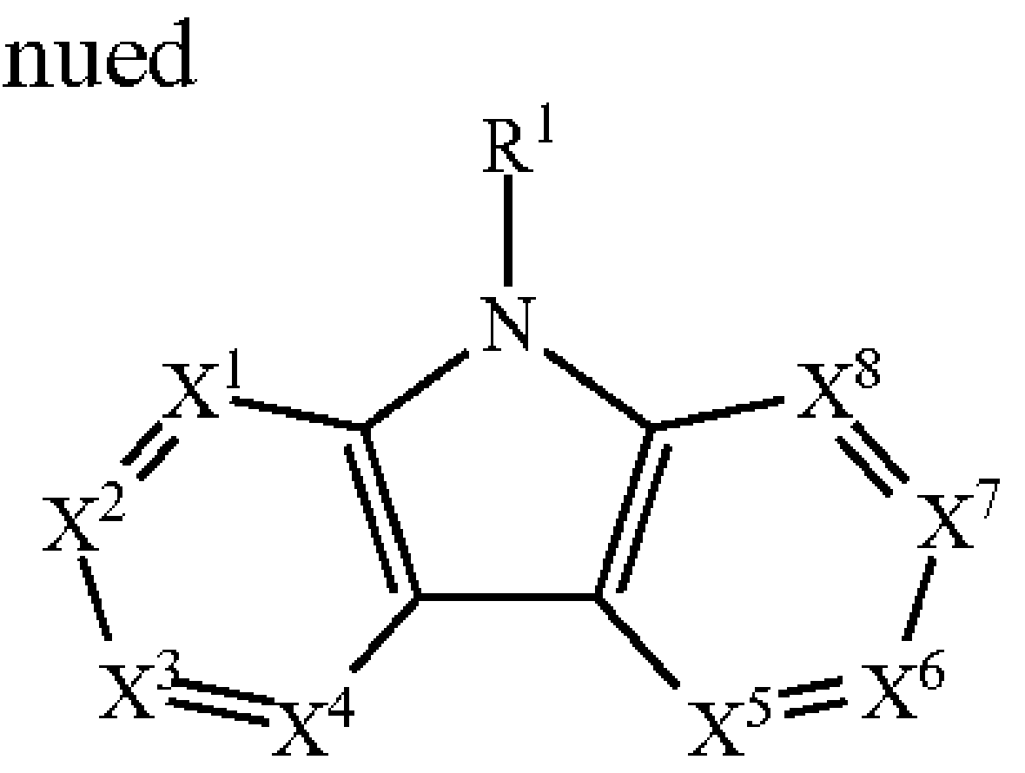
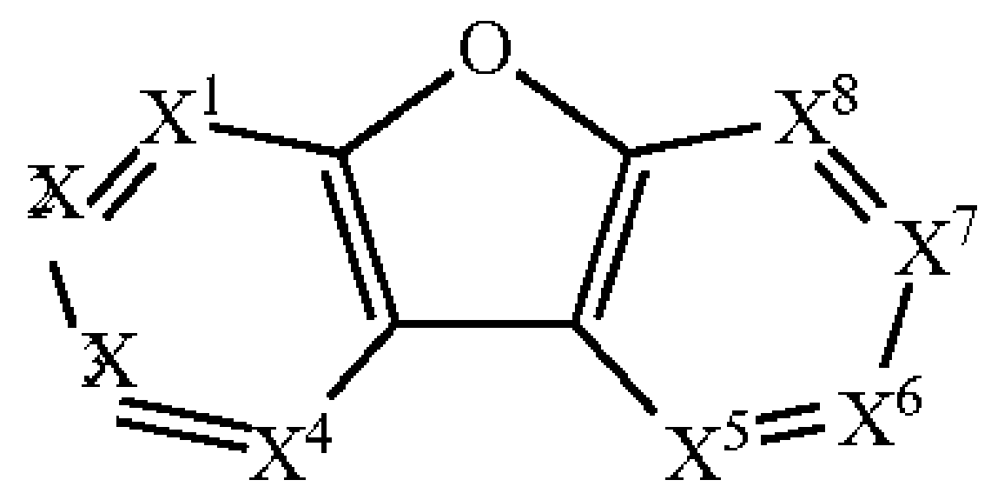
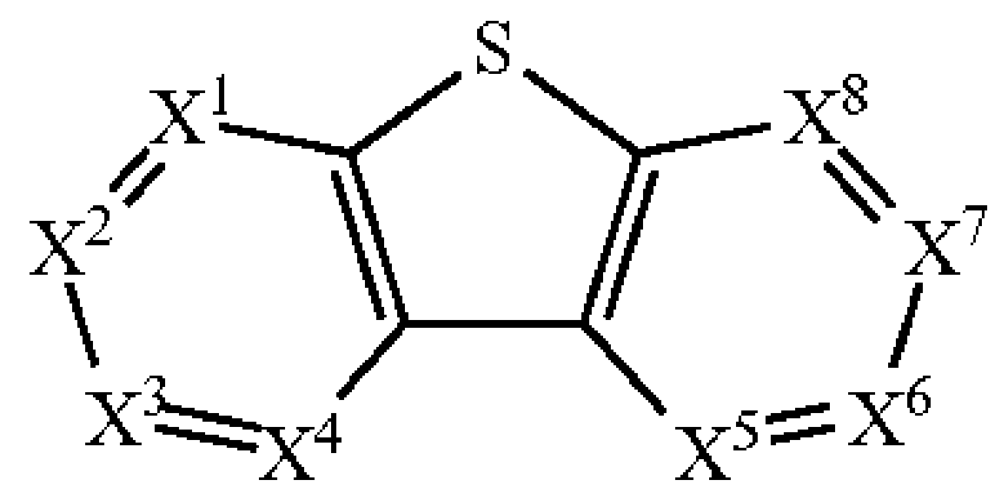
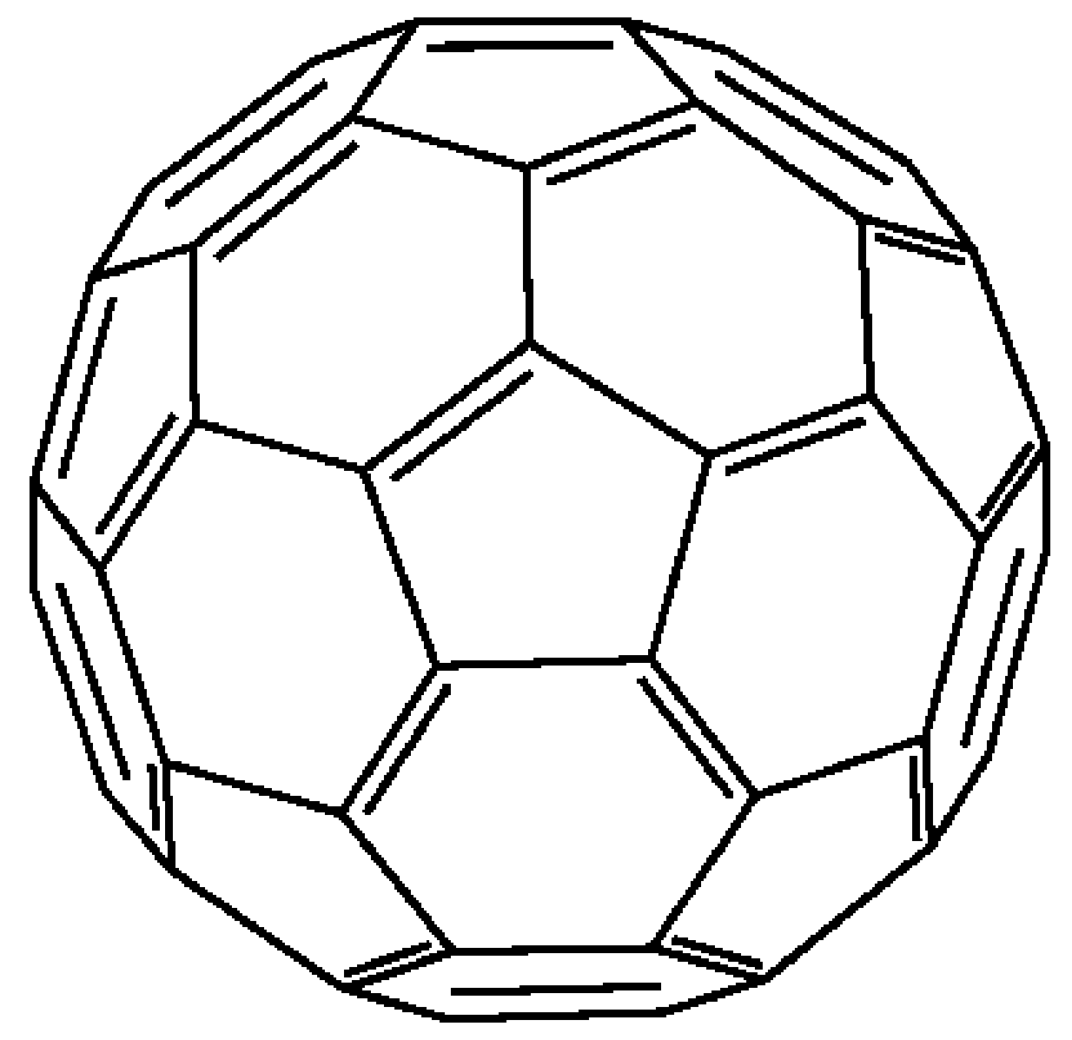


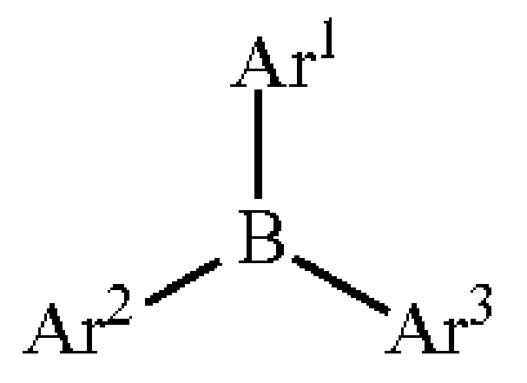












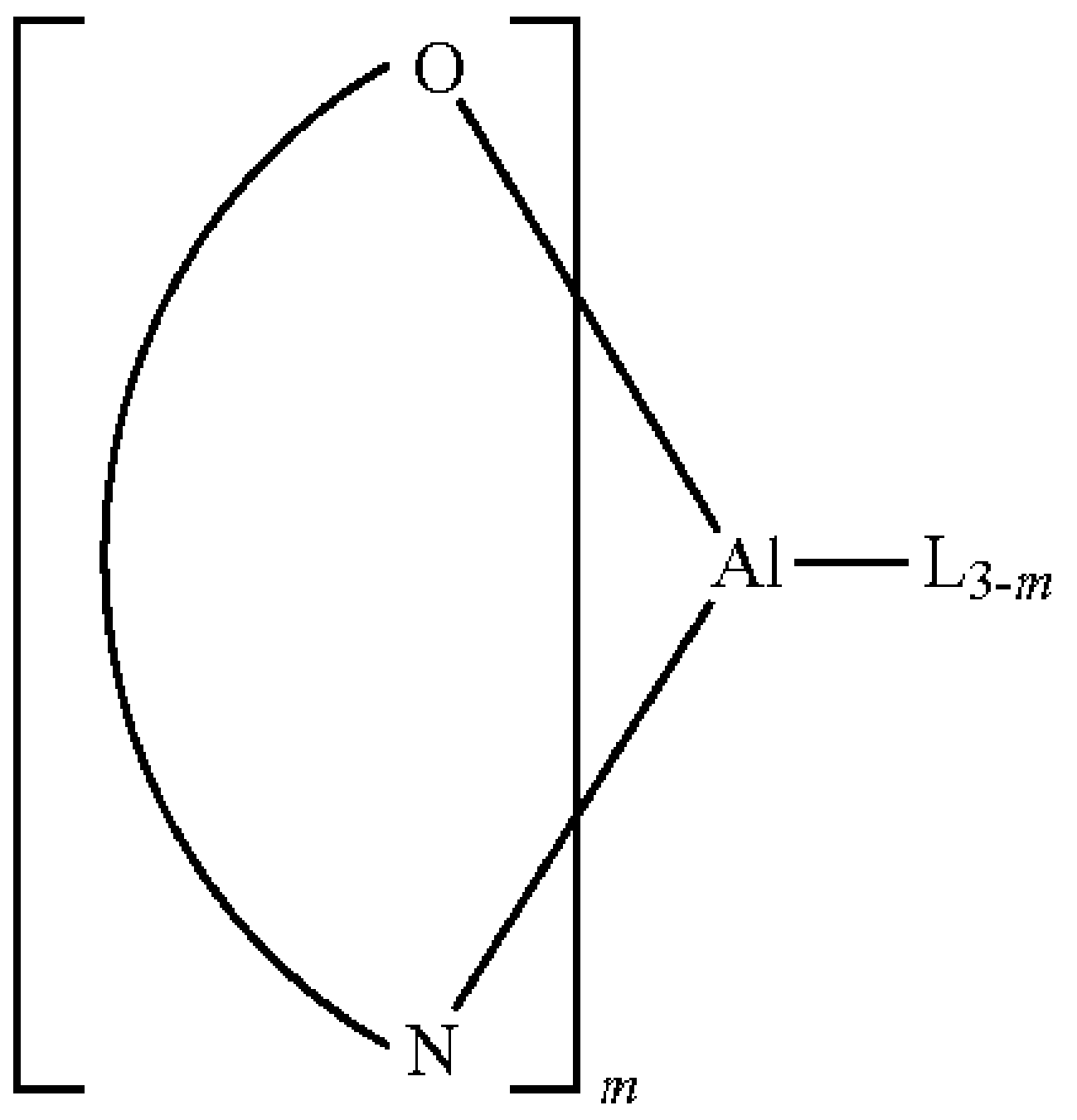
R^1 is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof, when it is aryl or heteroaryl, it has the similar definition as Ar's mentioned above.

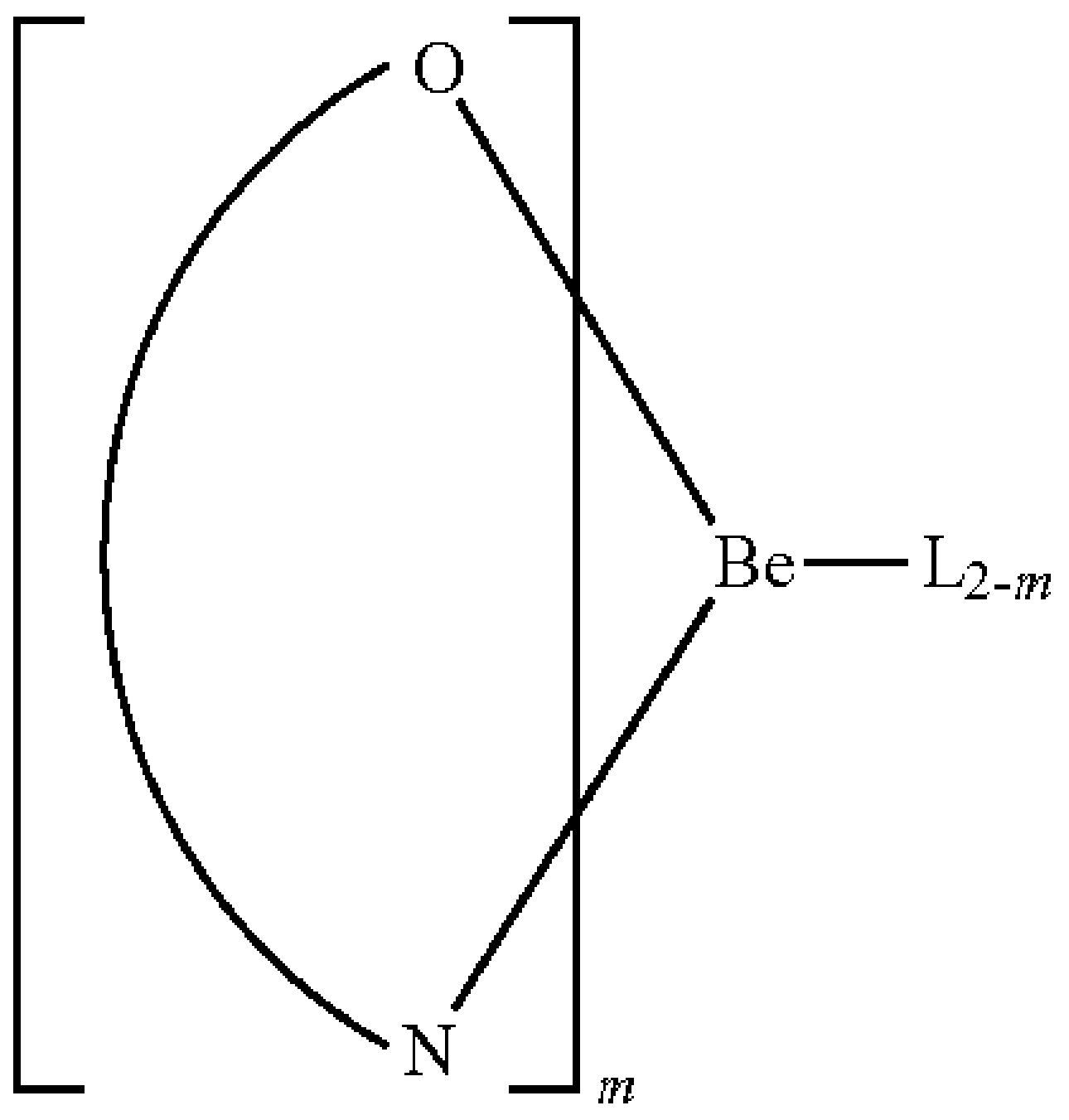
Ar^1 to Ar^3 has the similar definition as Ar's mentioned above.

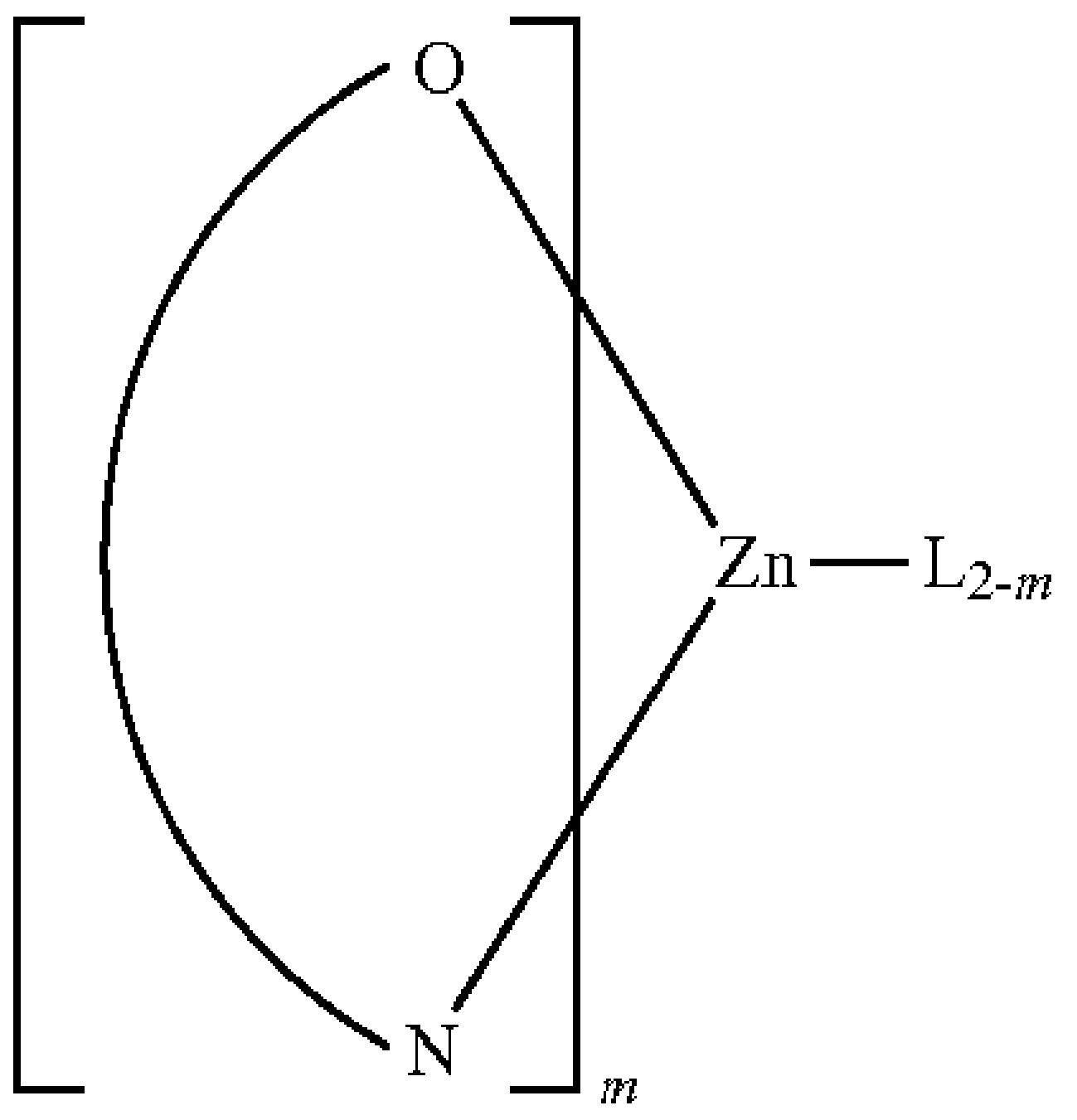
k is an integer from 0 to 20.

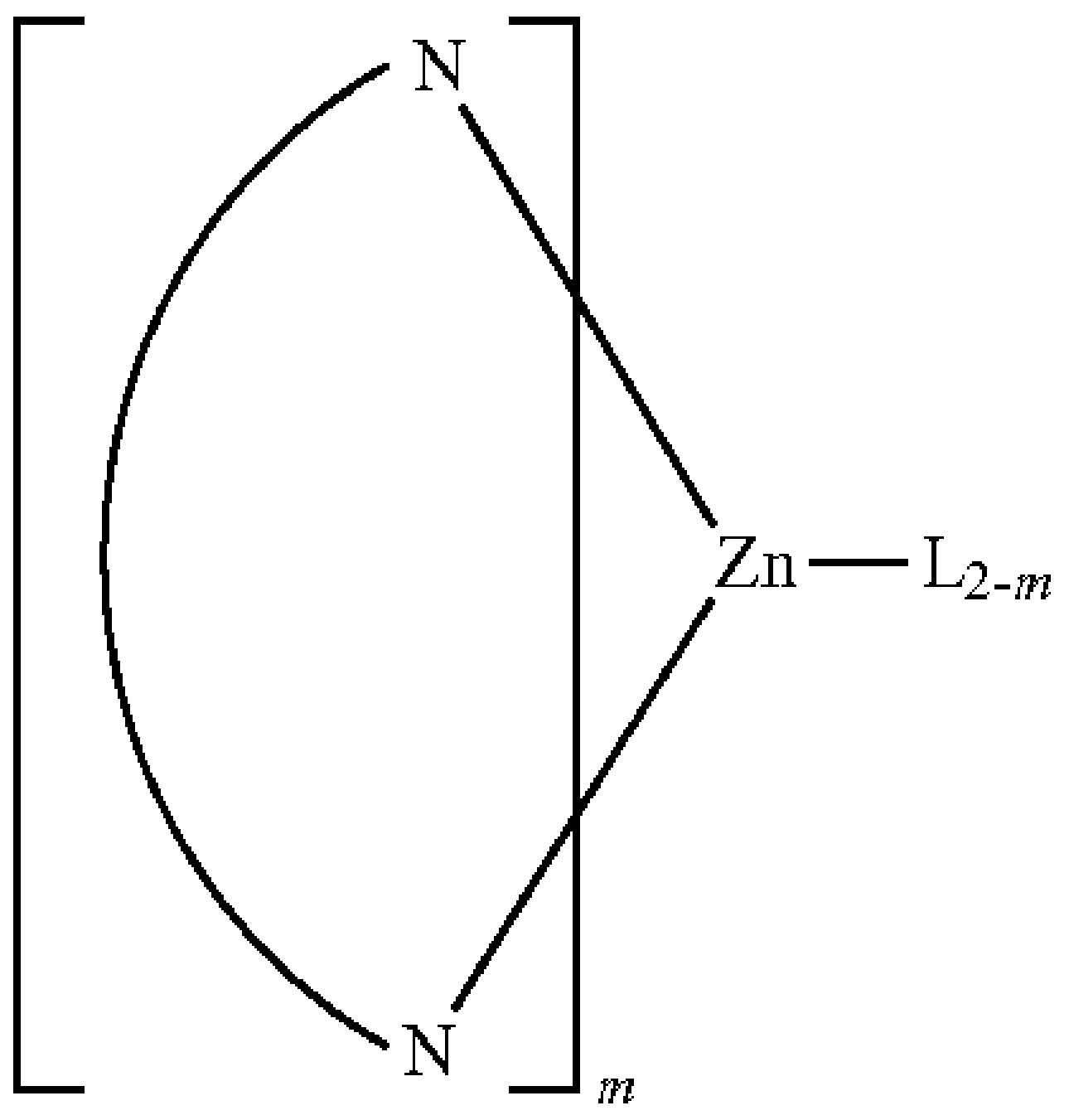
X^1 to X^8 is selected from C (including CH) or N.

In another aspect, the metal complexes used in ETL contains, but not limit to the following general formula:









(O—N) or (N—N) is a bidentate ligand, having metal coordinated to atoms O, N or N, N; L is an ancillary ligand; m is an integer value from 1 to the maximum number of ligands that may be attached to the metal.

In any above-mentioned compounds used in each layer of the OLED device, the hydrogen atoms can be partially or fully deuterated.

In addition to and/or in combination with the materials disclosed herein, many hole injection materials, hole transporting materials, host materials, dopant materials, exiton/hole blocking layer materials, electron transporting and electron injecting materials may be used in an OLED. Non-limiting examples of the materials that may be used in an OLED in combination with materials disclosed herein are listed in Table 4 below. Table 4 lists non-limiting classes of materials, non-limiting examples of compounds for each class, and references that disclose the materials.

TABLE 4

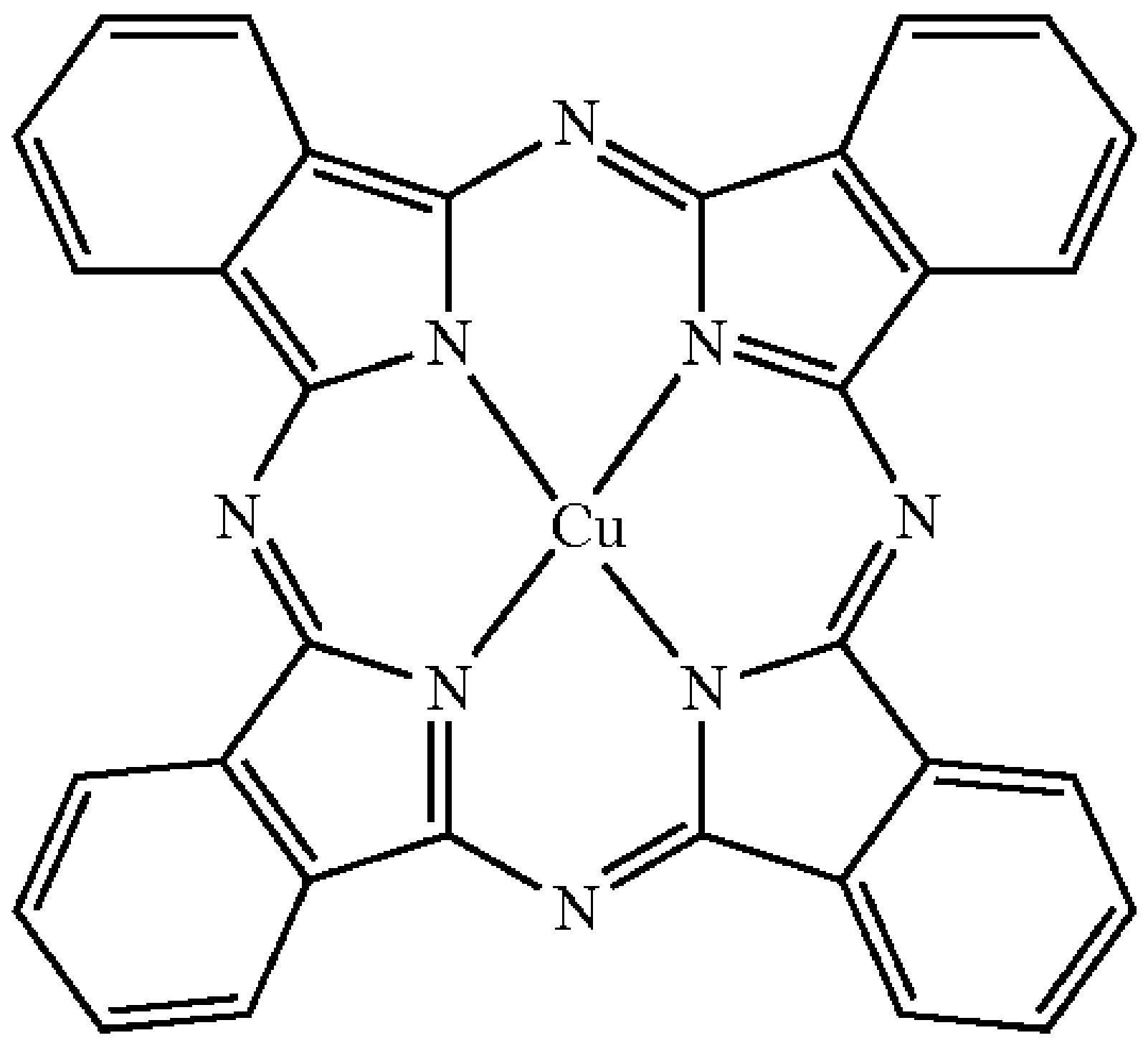
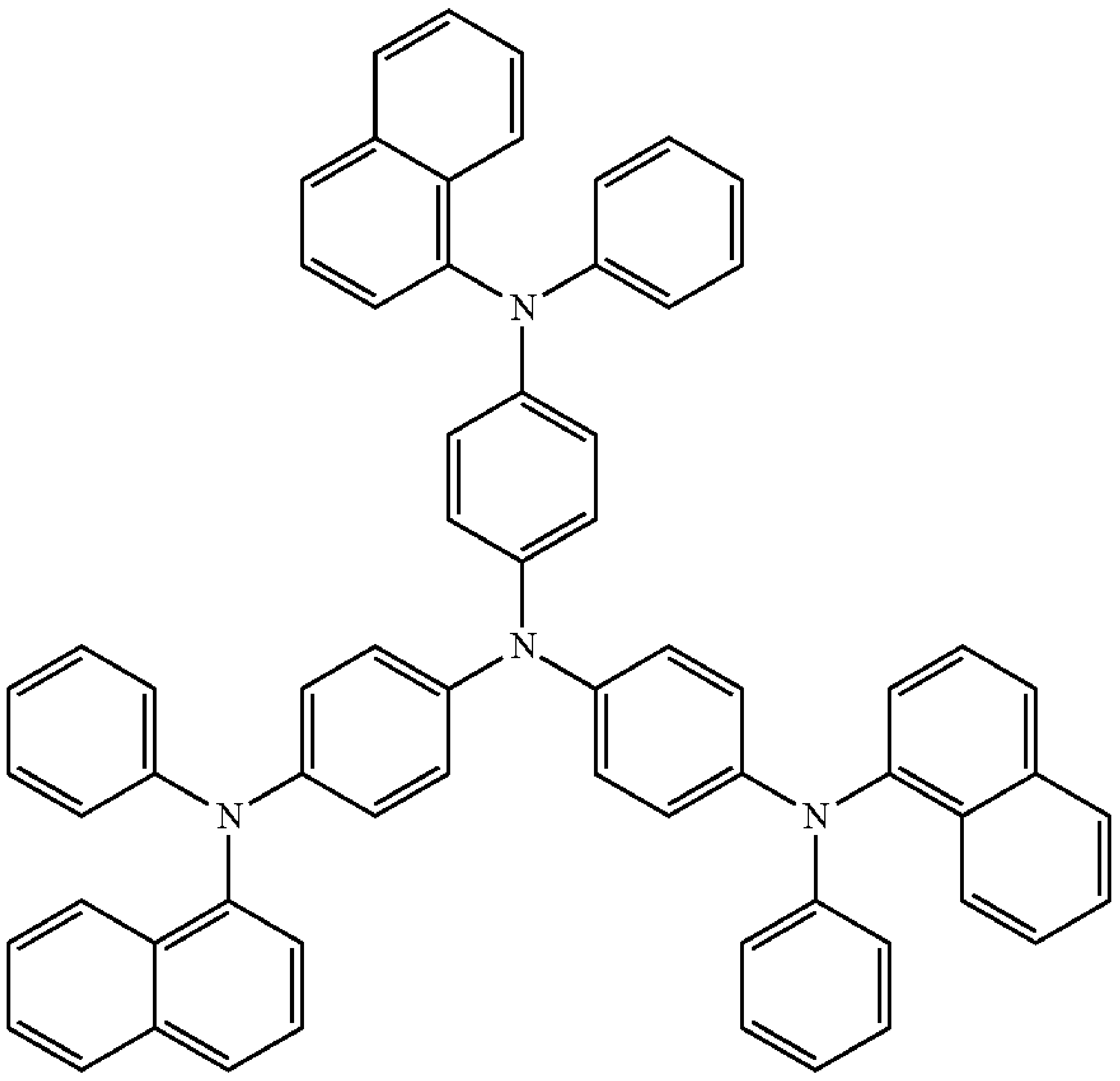
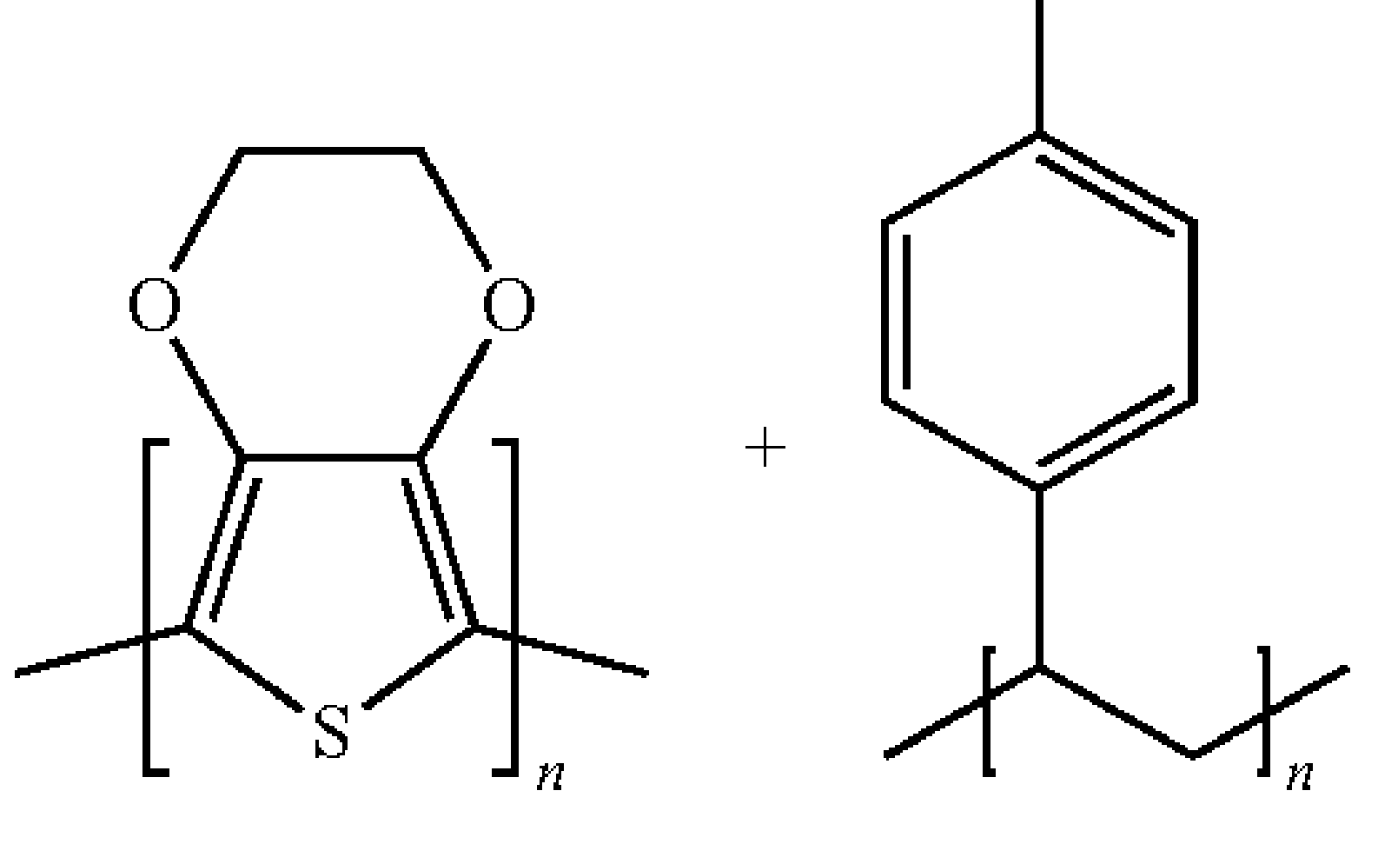
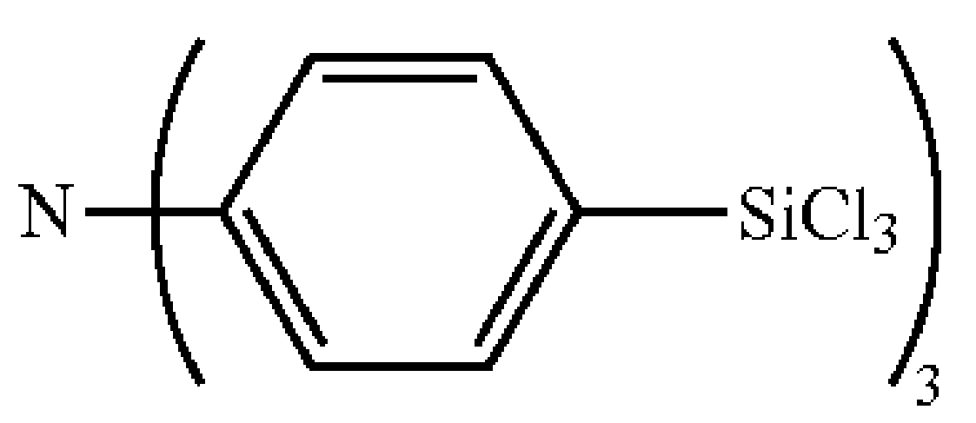
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Hole injection materials	
Phthalocyanine and porphryin compounds		Appl. Phys. Lett. 69, 2160 (1996)
Starburst triarylamines		J. Lumin. 72-74, 985 (1997)
CF_x Fluorohydrocarbon polymer	$-\!\!\!+CH_xF_y+\!\!\!-_n$	Appl. Phys. Lett. 78, 673 (2001)
Conducting polymers (e.g., PEDOT:PSS, polyaniline, polypthiophene)		Synth. Met. 87, 171 (1997) WO2007002683
Phosphonic acid and sliane SAMs		US20030162053

TABLE 4-continued

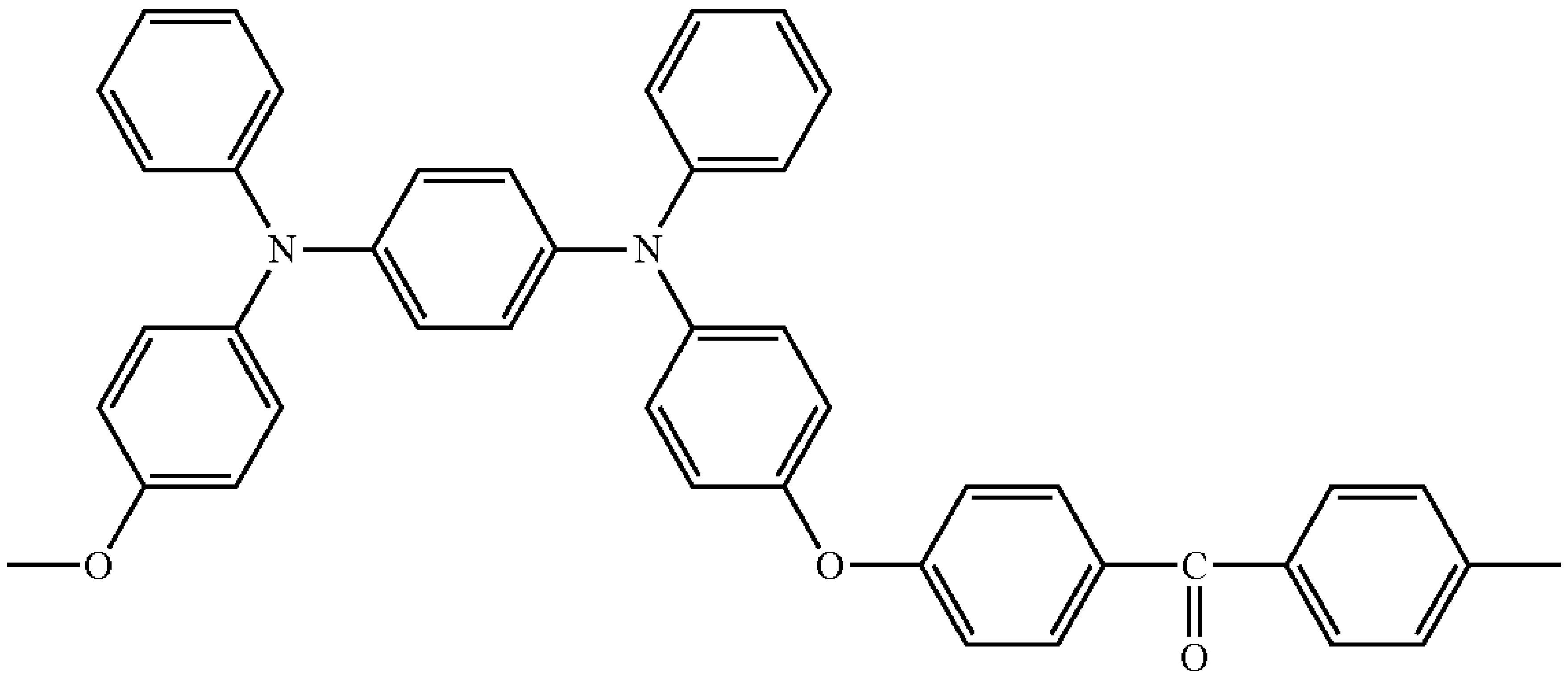
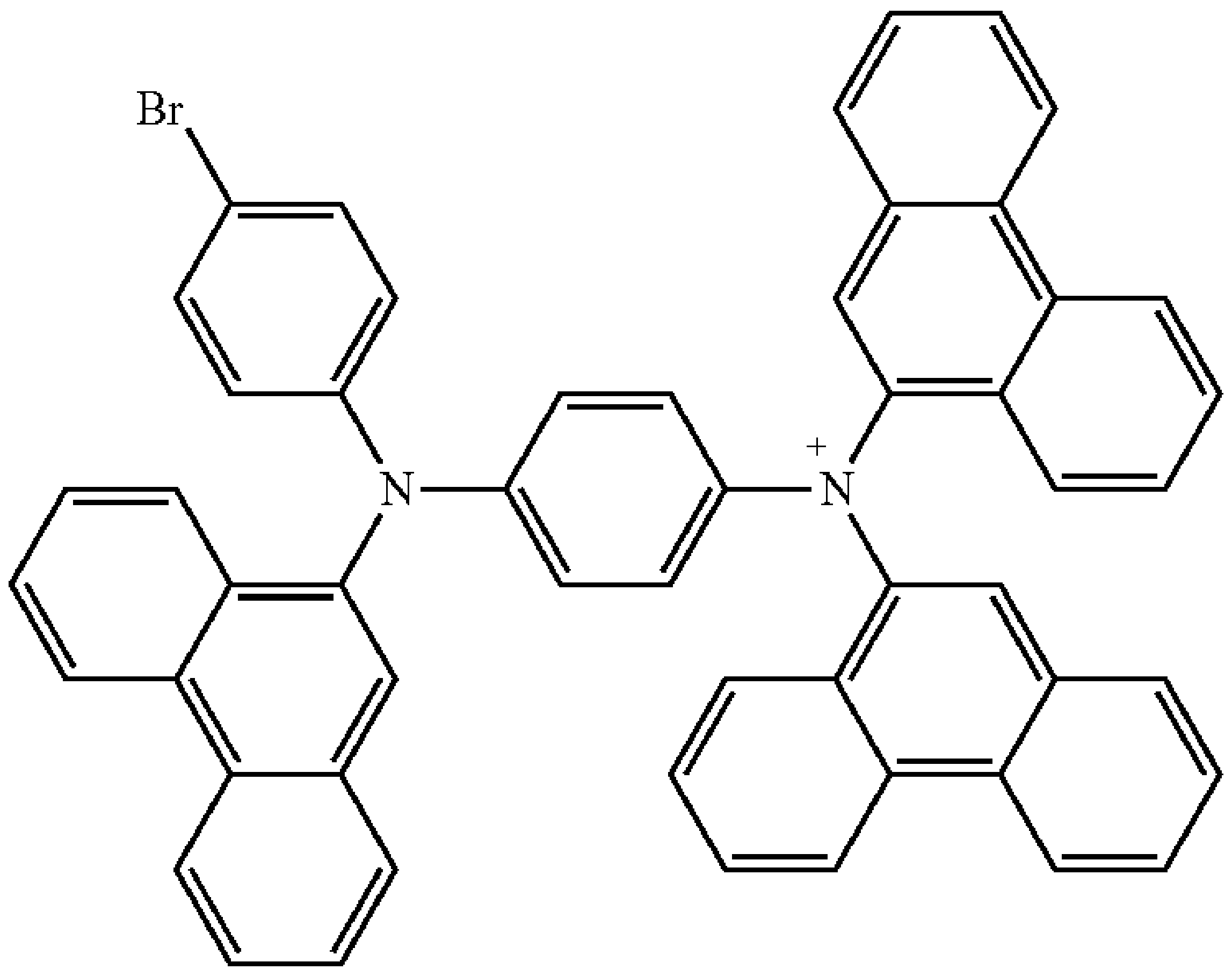
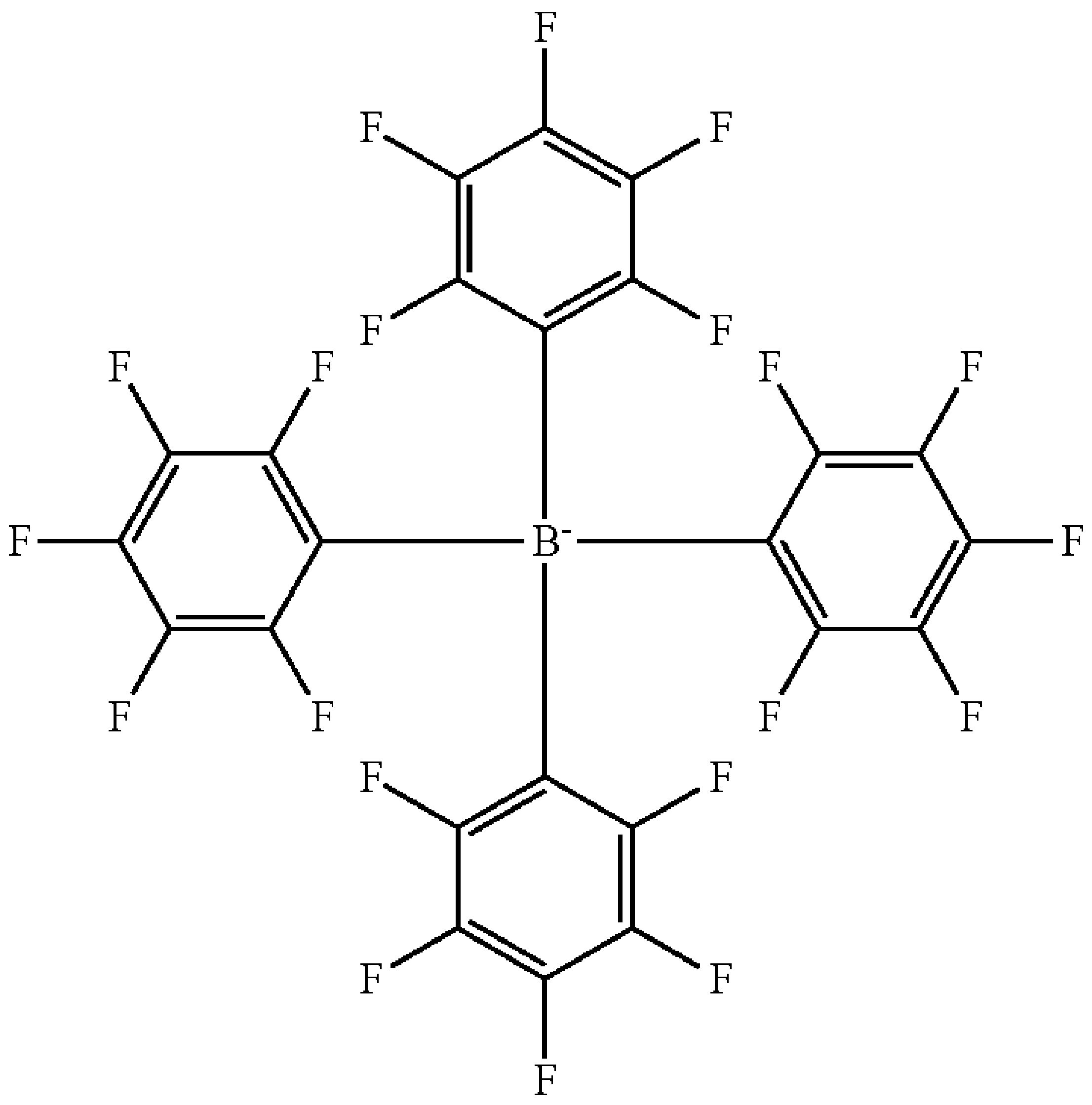
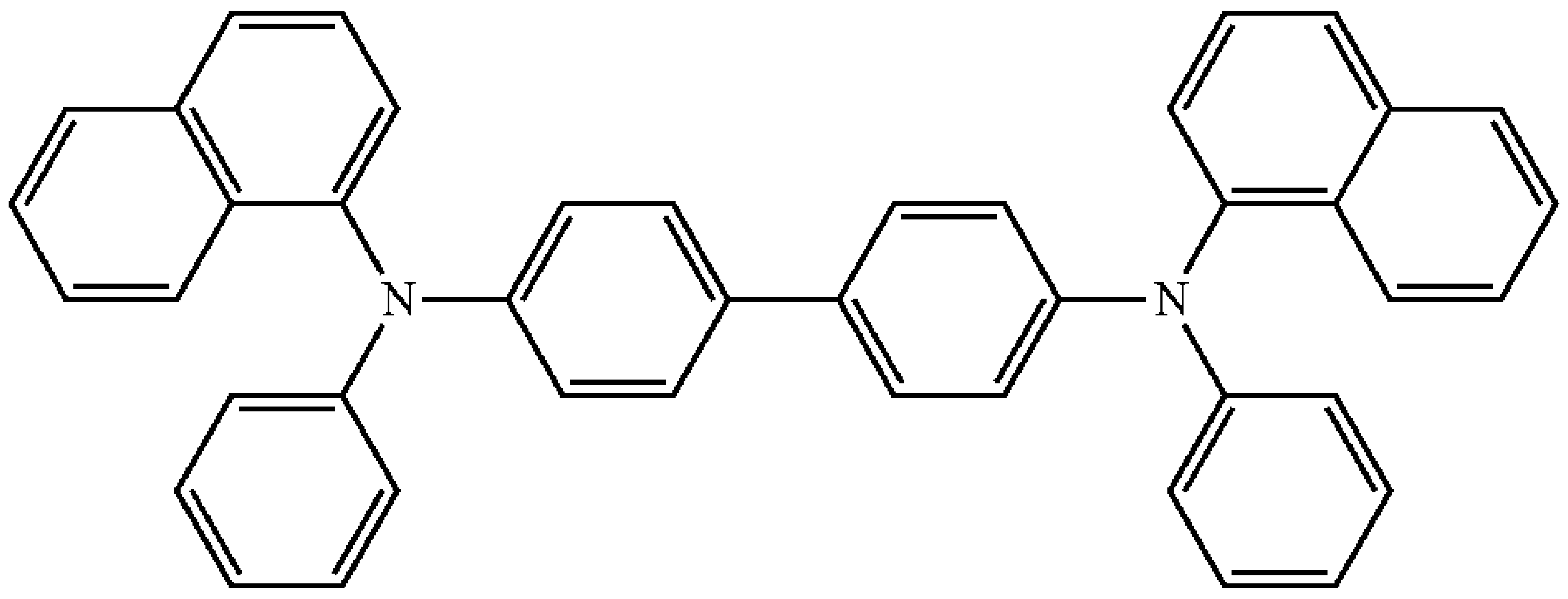
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triarylamine or polythiophene polymers with conductivity dopants	 and  	EP1725079A1
Organic compounds with conductive inorganic compounds, such as molybdenum and tungsten oxides	 $+ \ \mathrm{MoO}_x$	US20050123751 SID Symposium Digest, 37, 923 (2006) WO2009018009

TABLE 4-continued

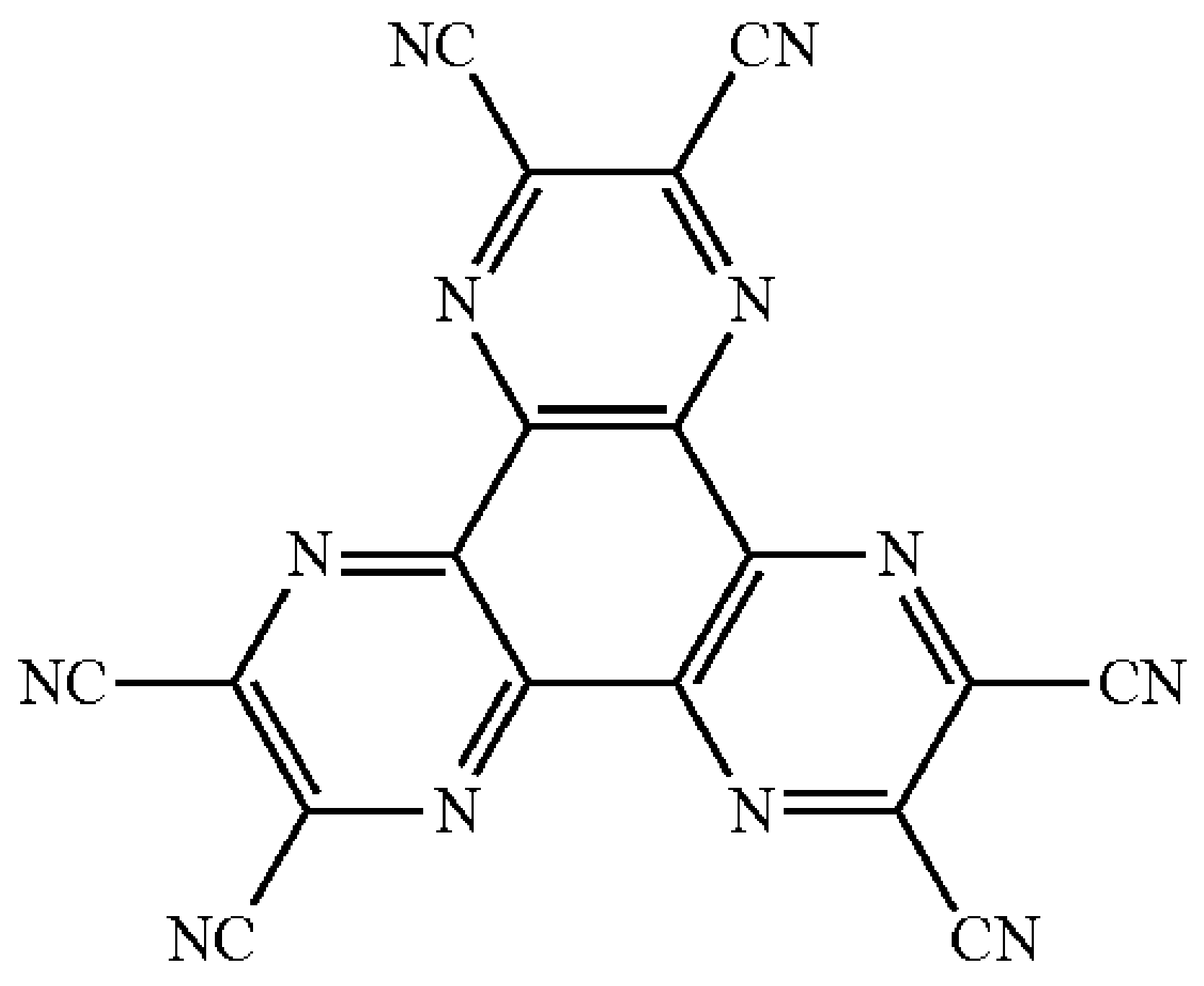
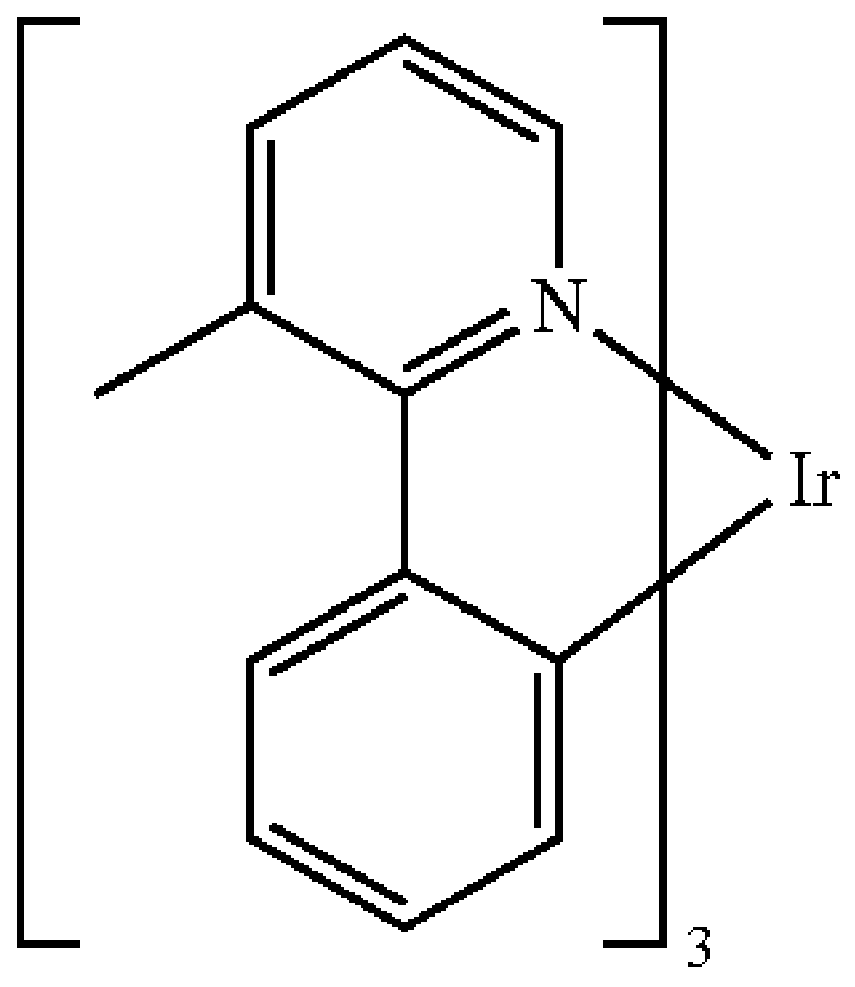
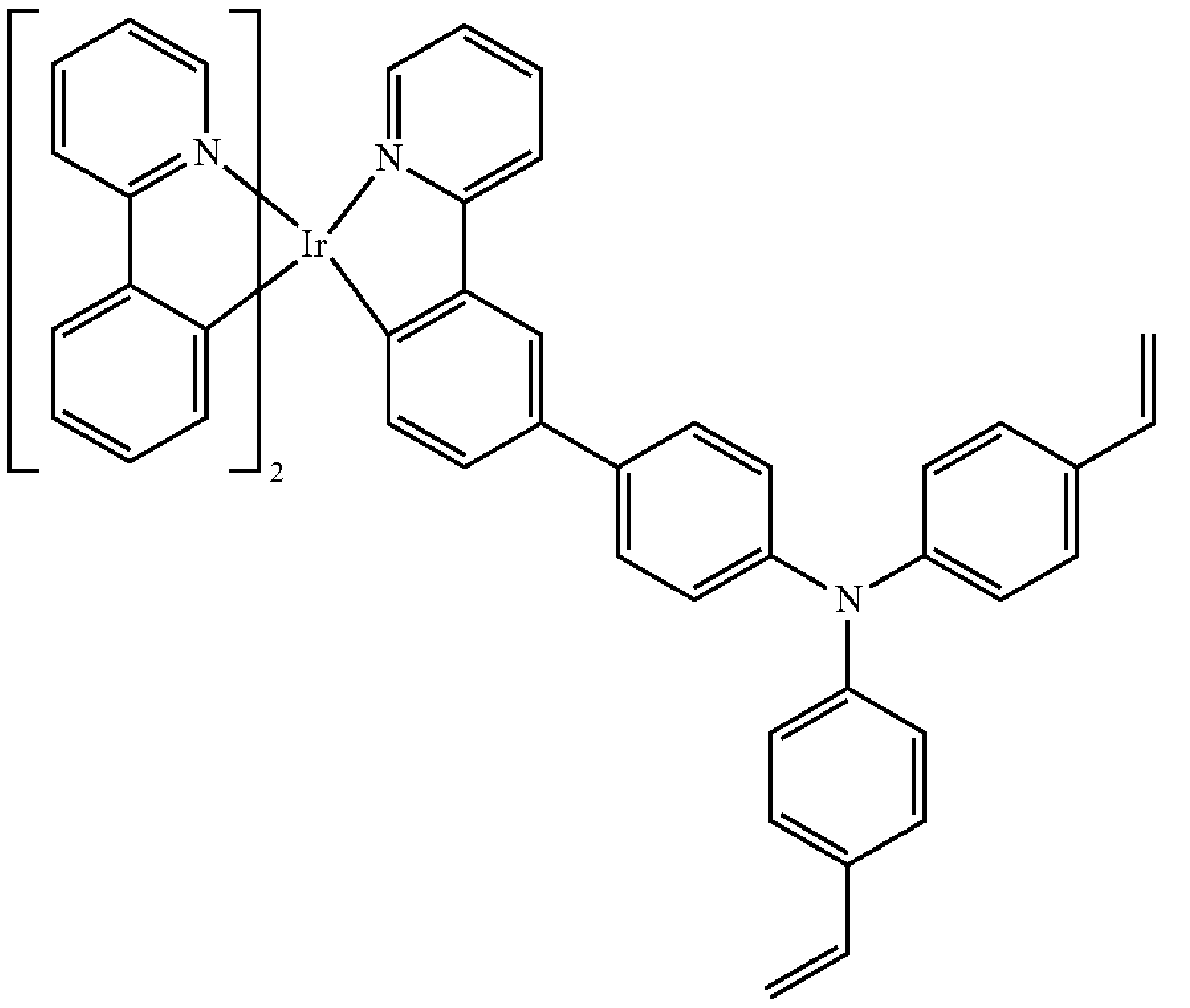
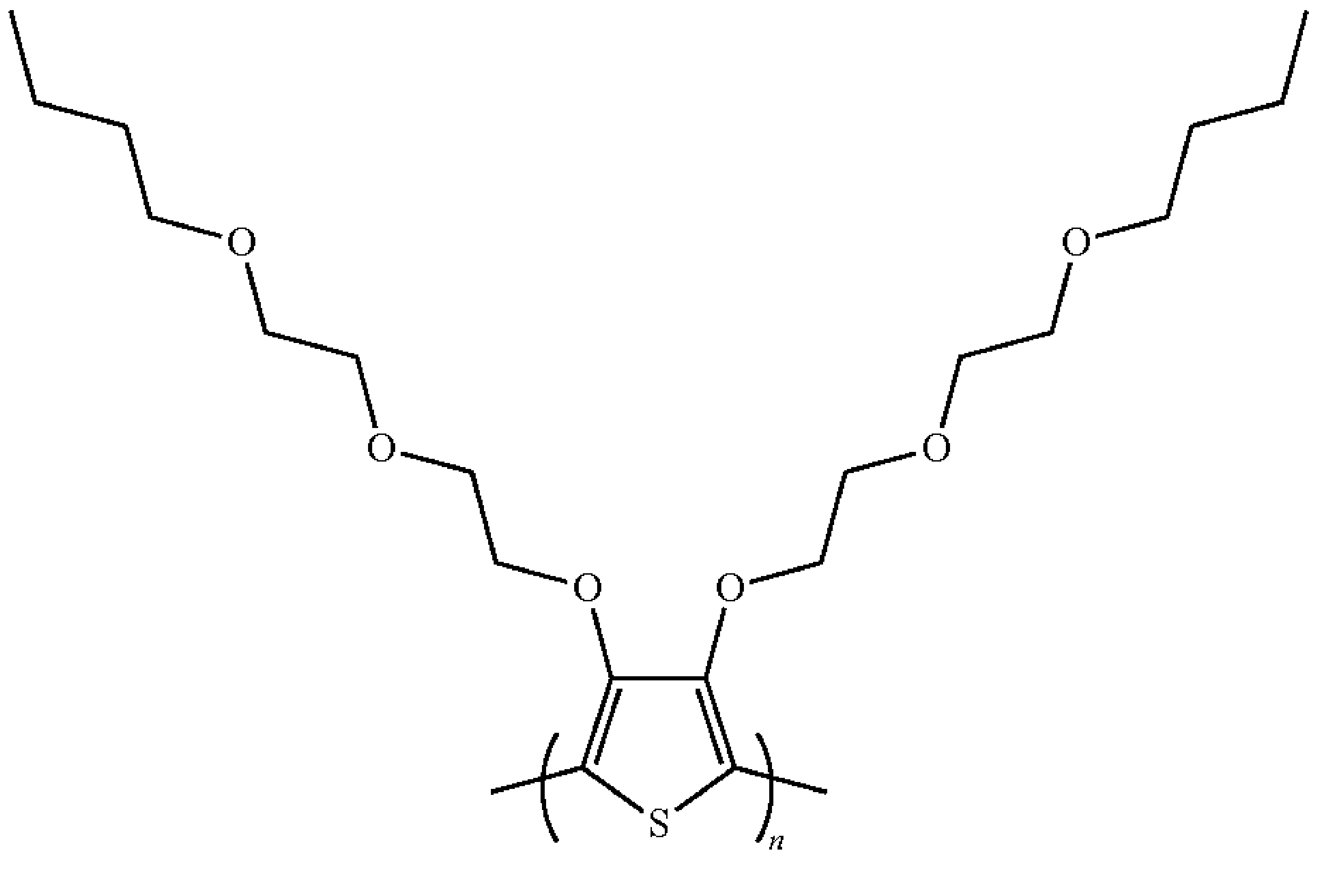
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
n-type semiconducting organic complexes		US20020158242
Metal organometallic complexes		US20060240279
Cross-linkable compounds		US20080220265
Polythiophene based polymers and copolymers		WO 2011075644 EP2350216

TABLE 4-continued

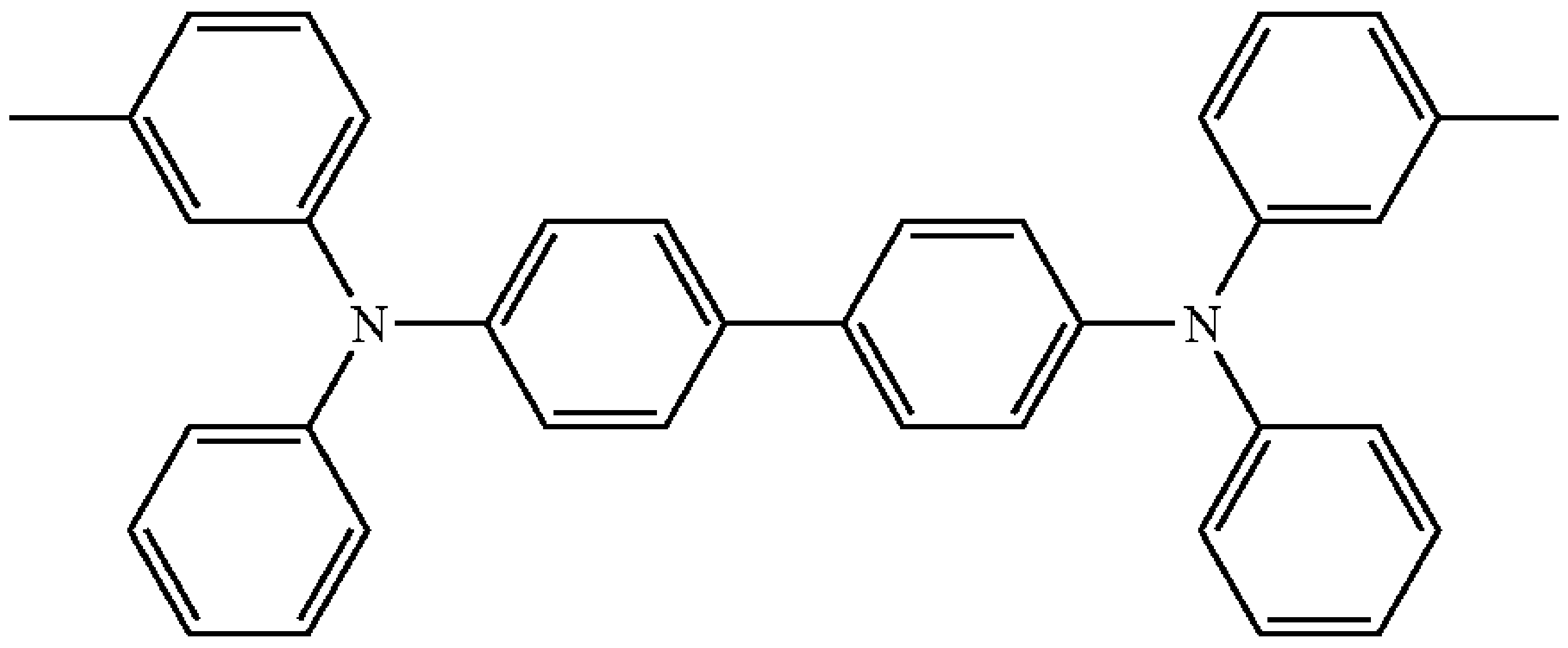
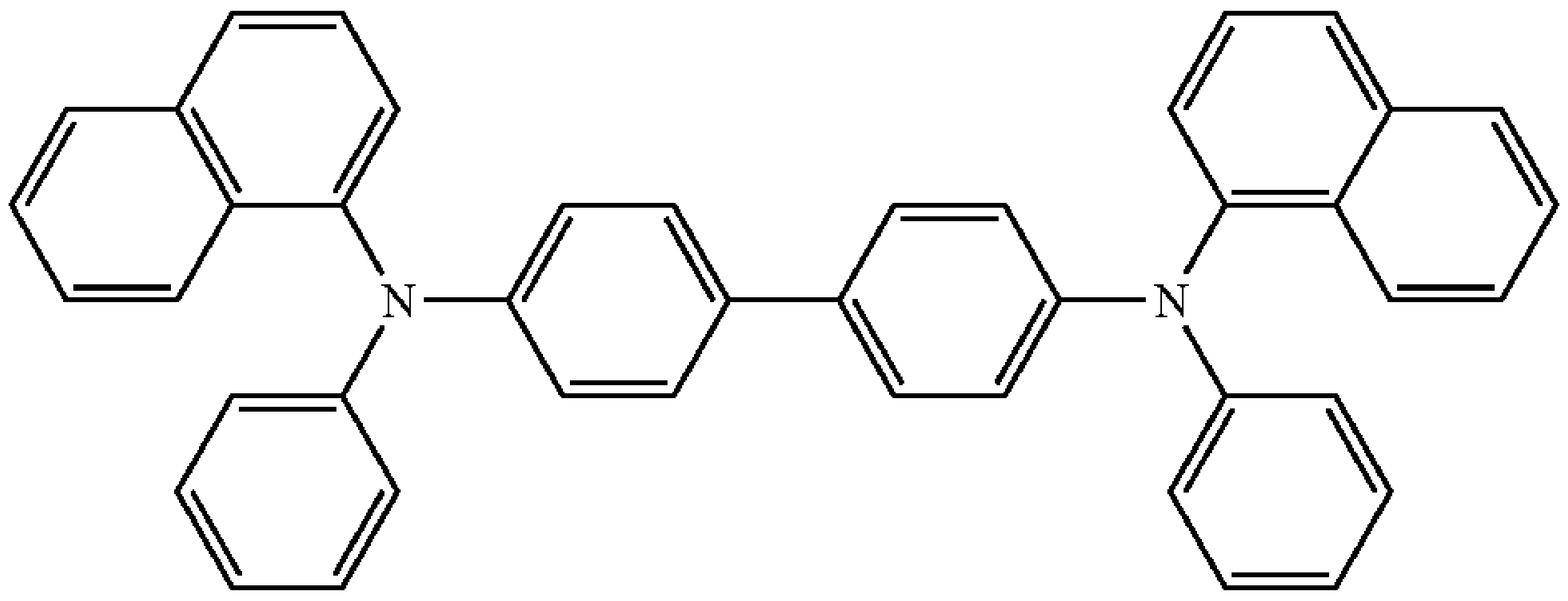
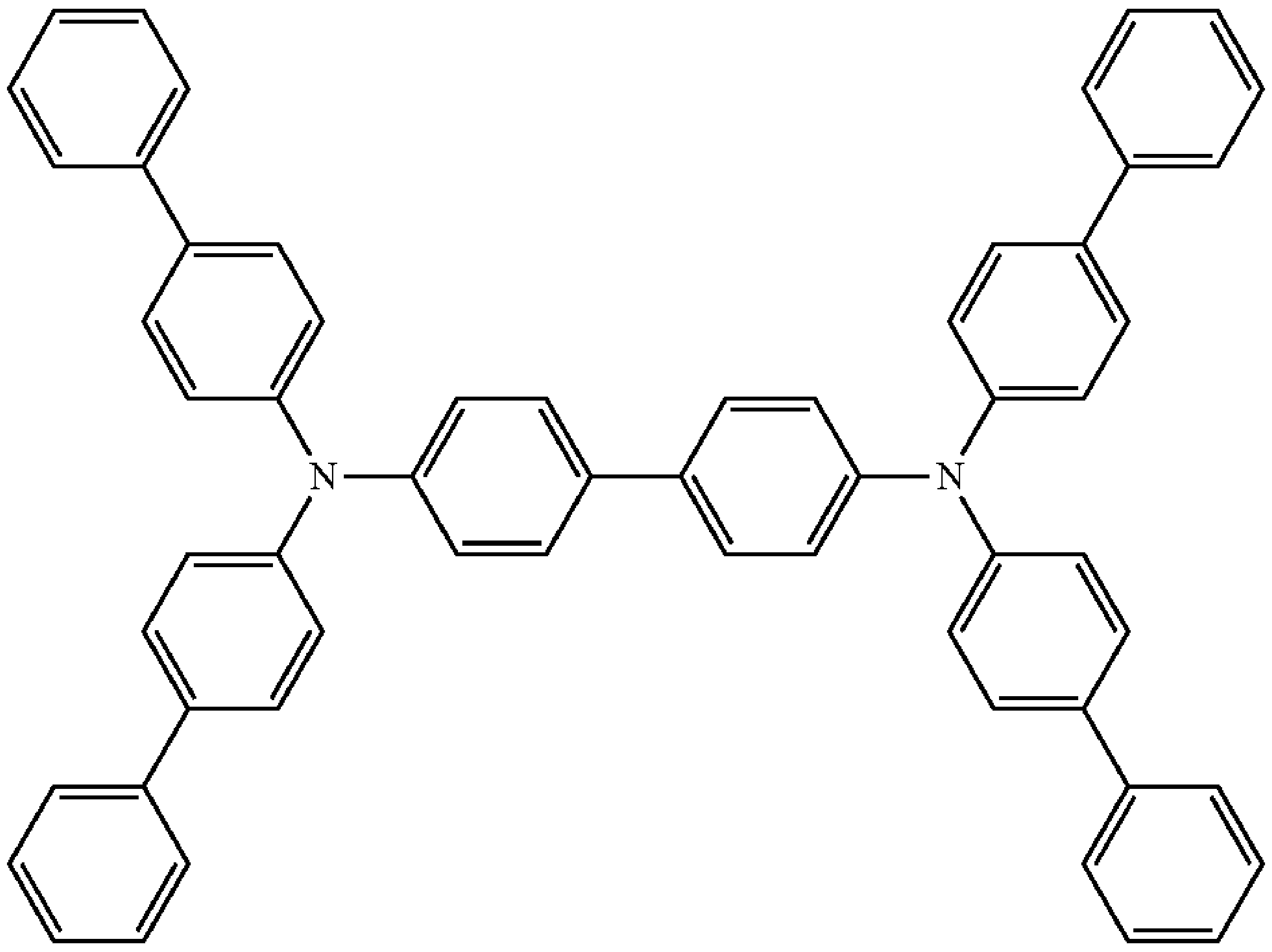
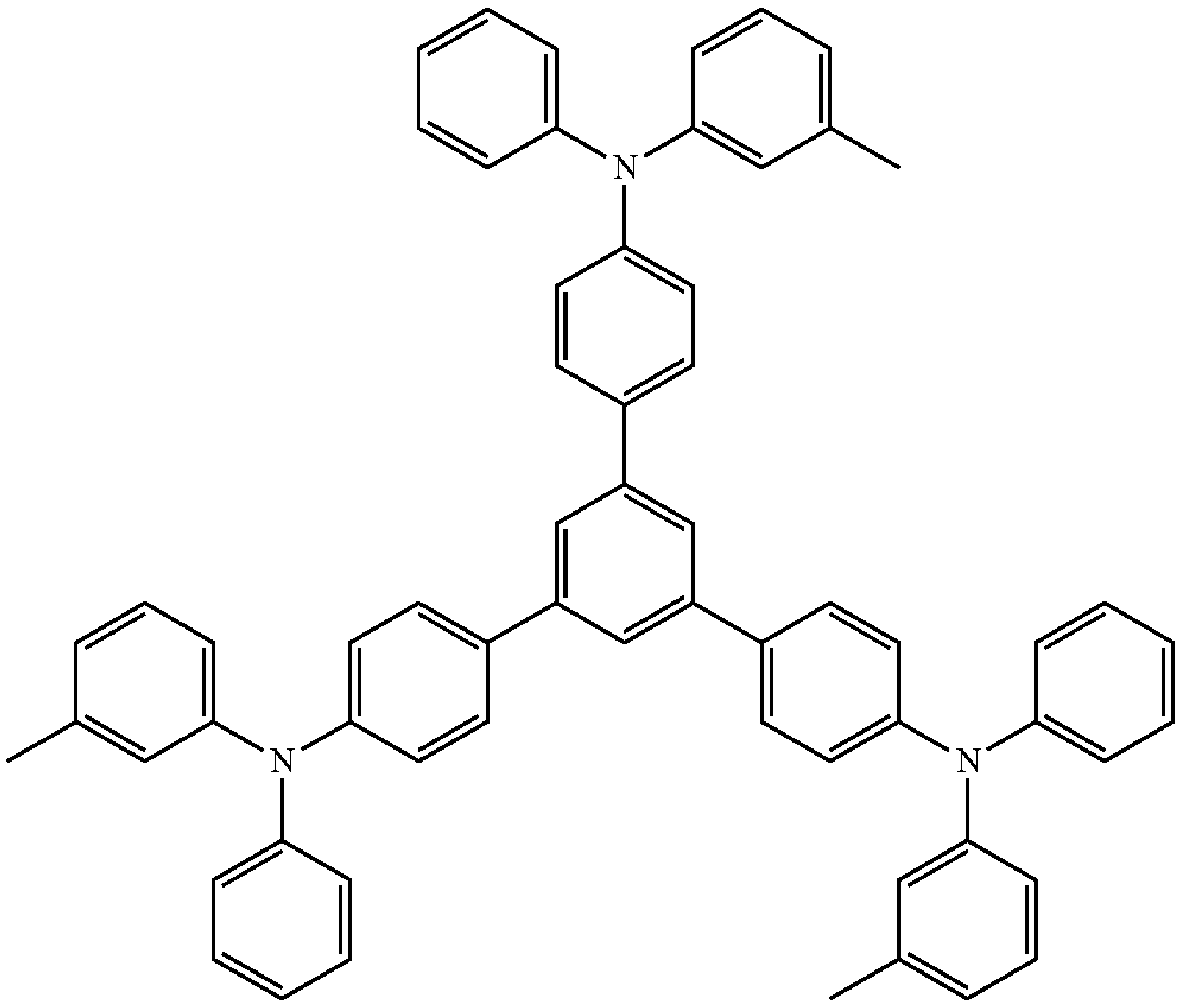
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
	Hole transporting materials	
Triarylamines (e.g., TPD, α-NPD)		Appl. Phys. Lett. 51, 913 (1987)
		U.S. Pat. No. 5,061,569
		EP650955
		J. Mater. Chem. 3, 319 (1993)

TABLE 4-continued

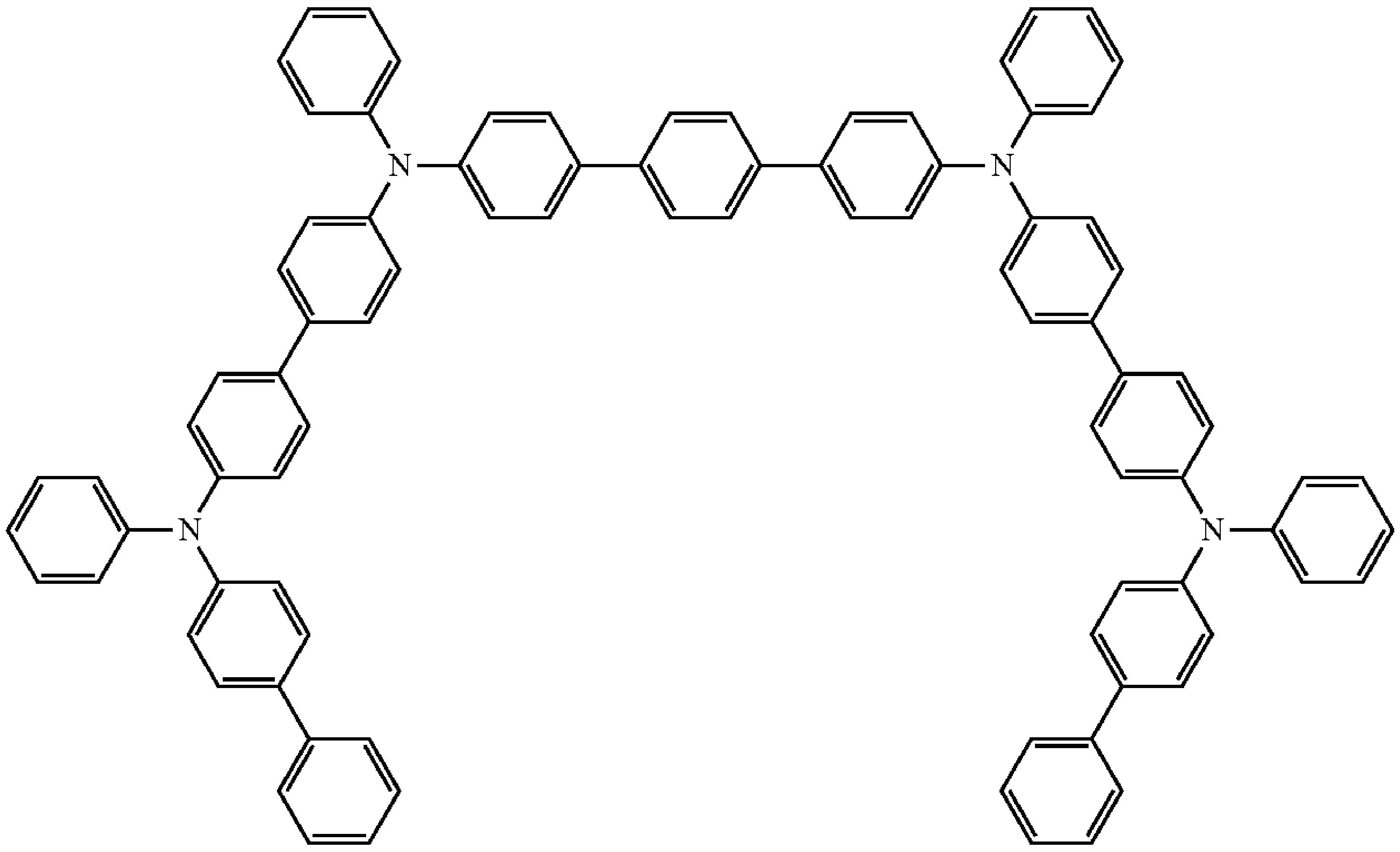
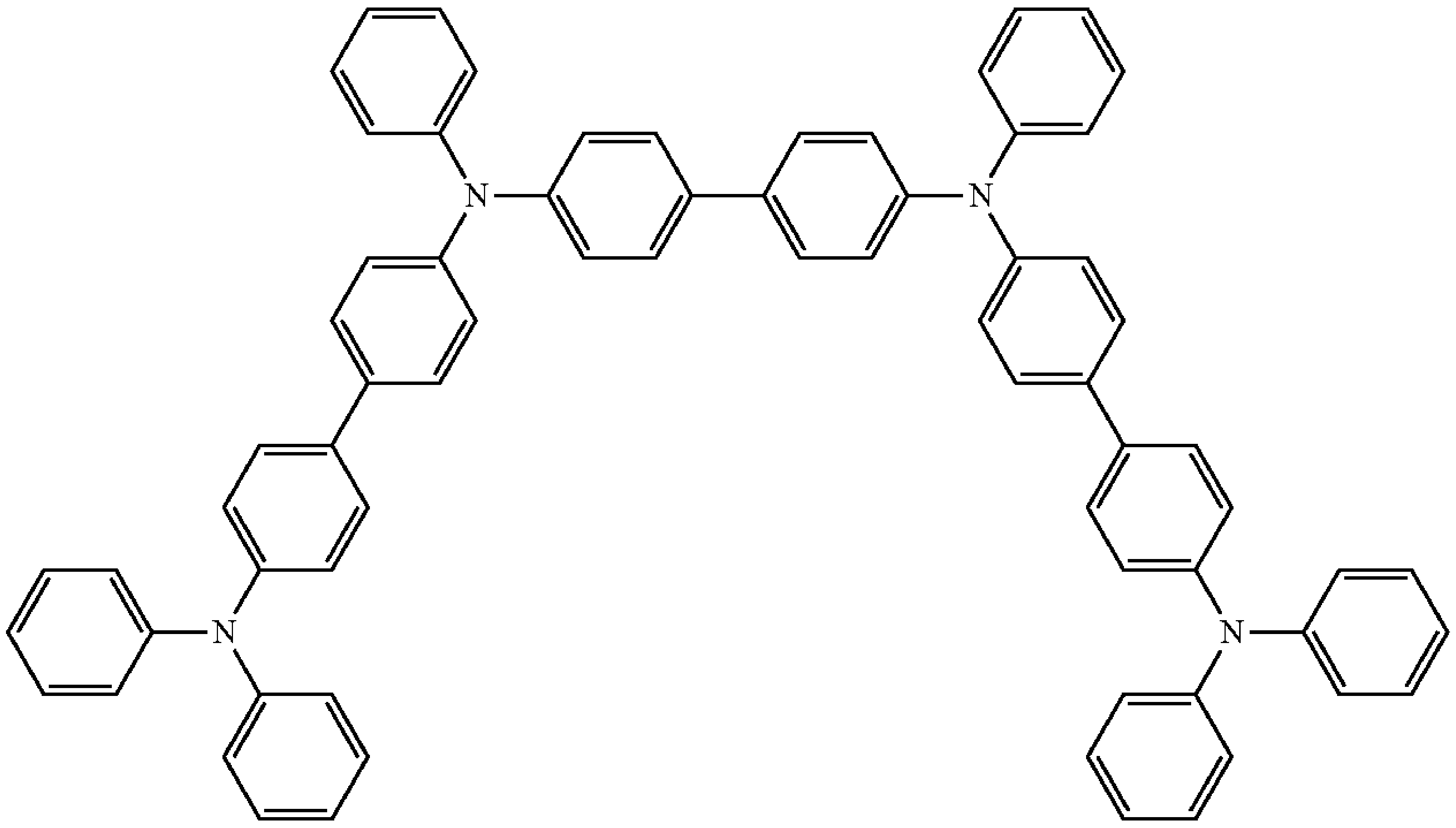
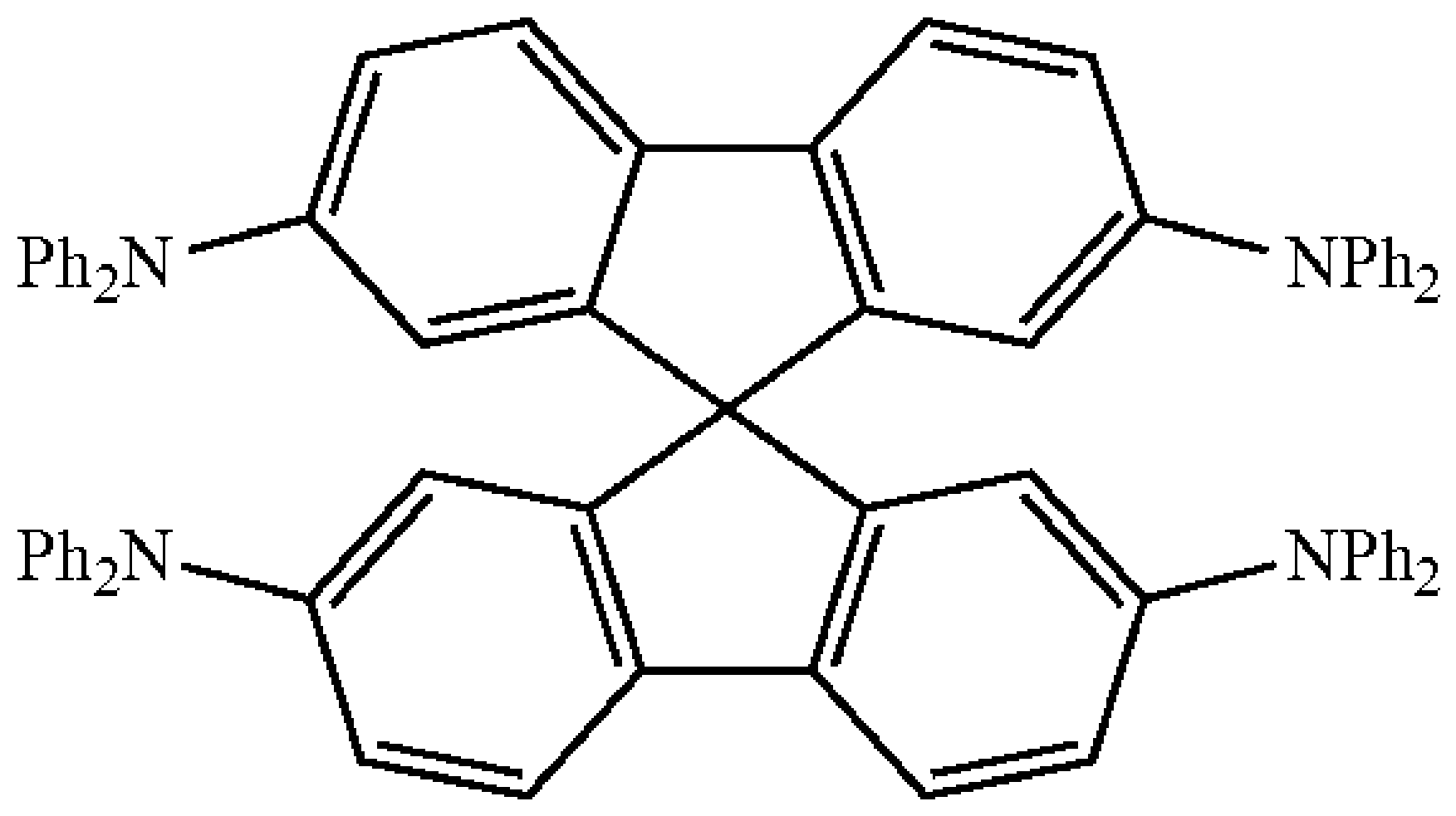
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		Appl. Phys. Lett. 90, 183503 (2007)
		Appl. Phys. Lett. 90, 183503 (2007)
Triaylamine on spirofluorene core		Synth. Met. 91, 209 (1997)

TABLE 4-continued

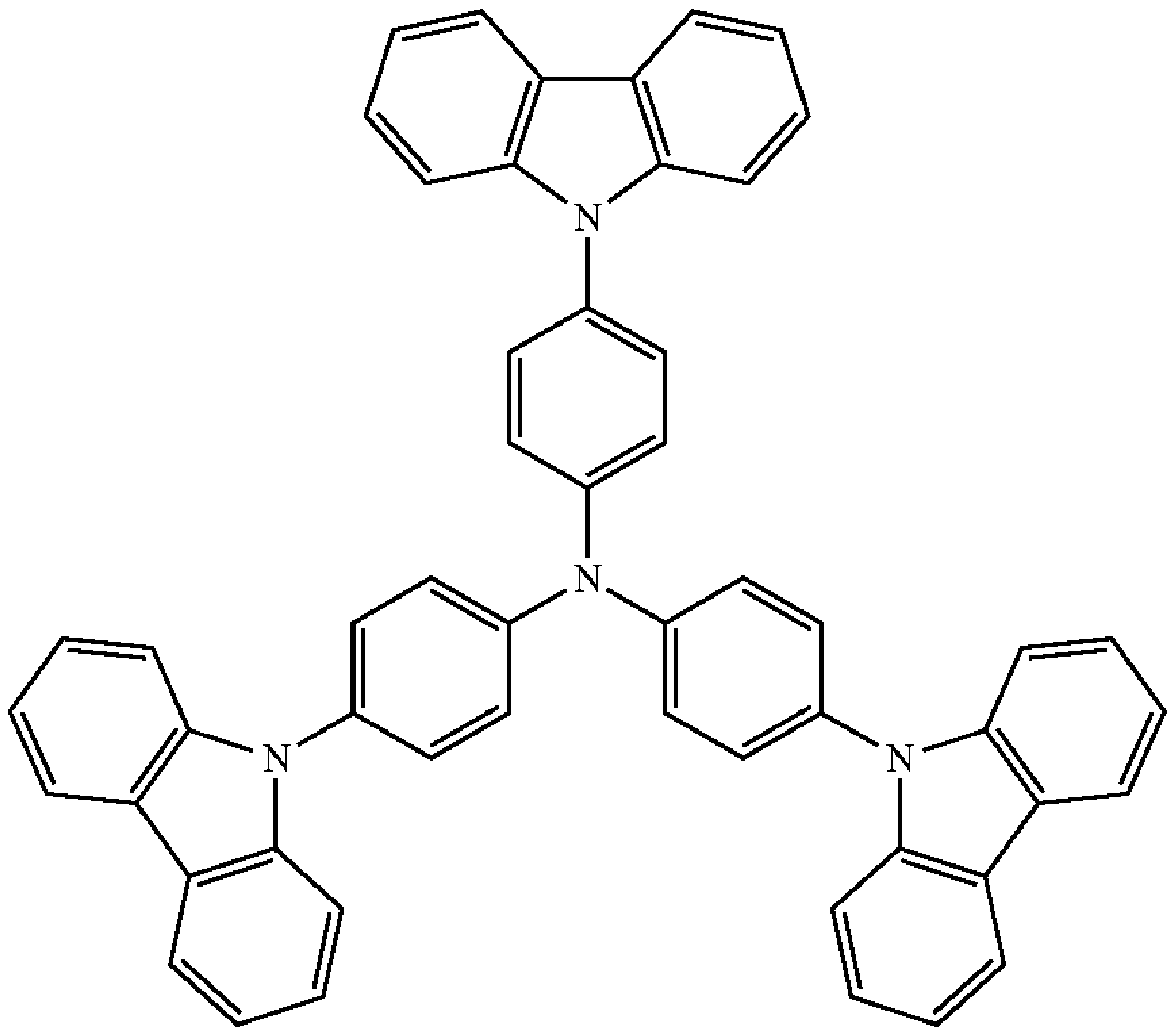
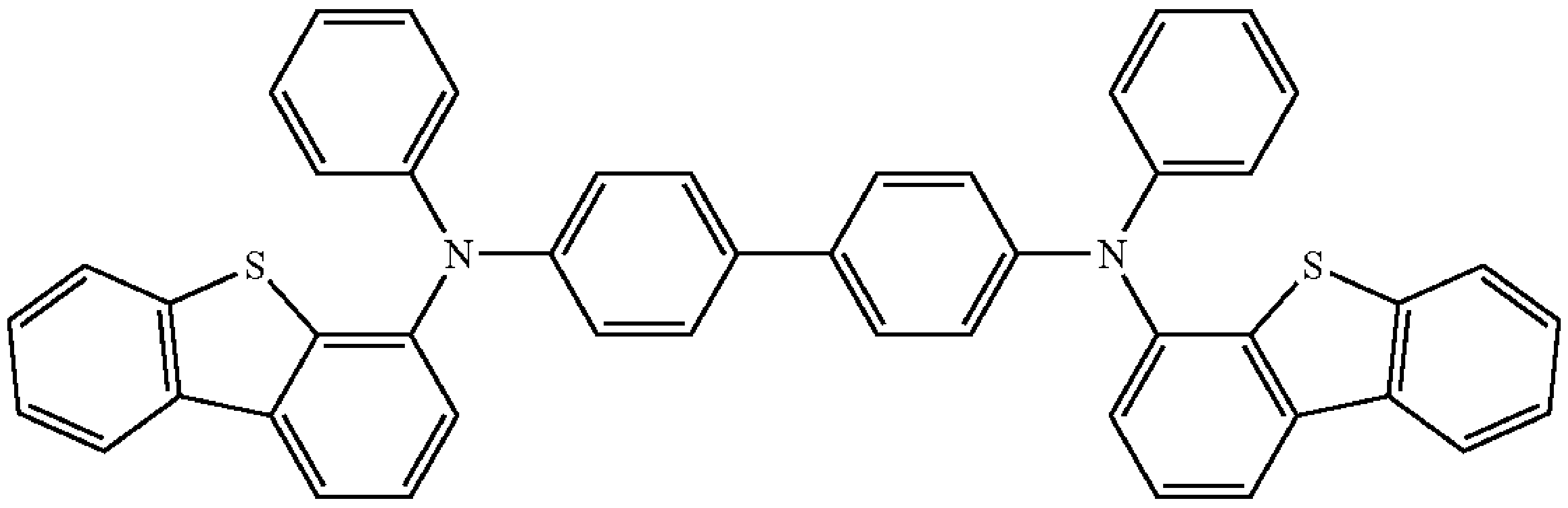
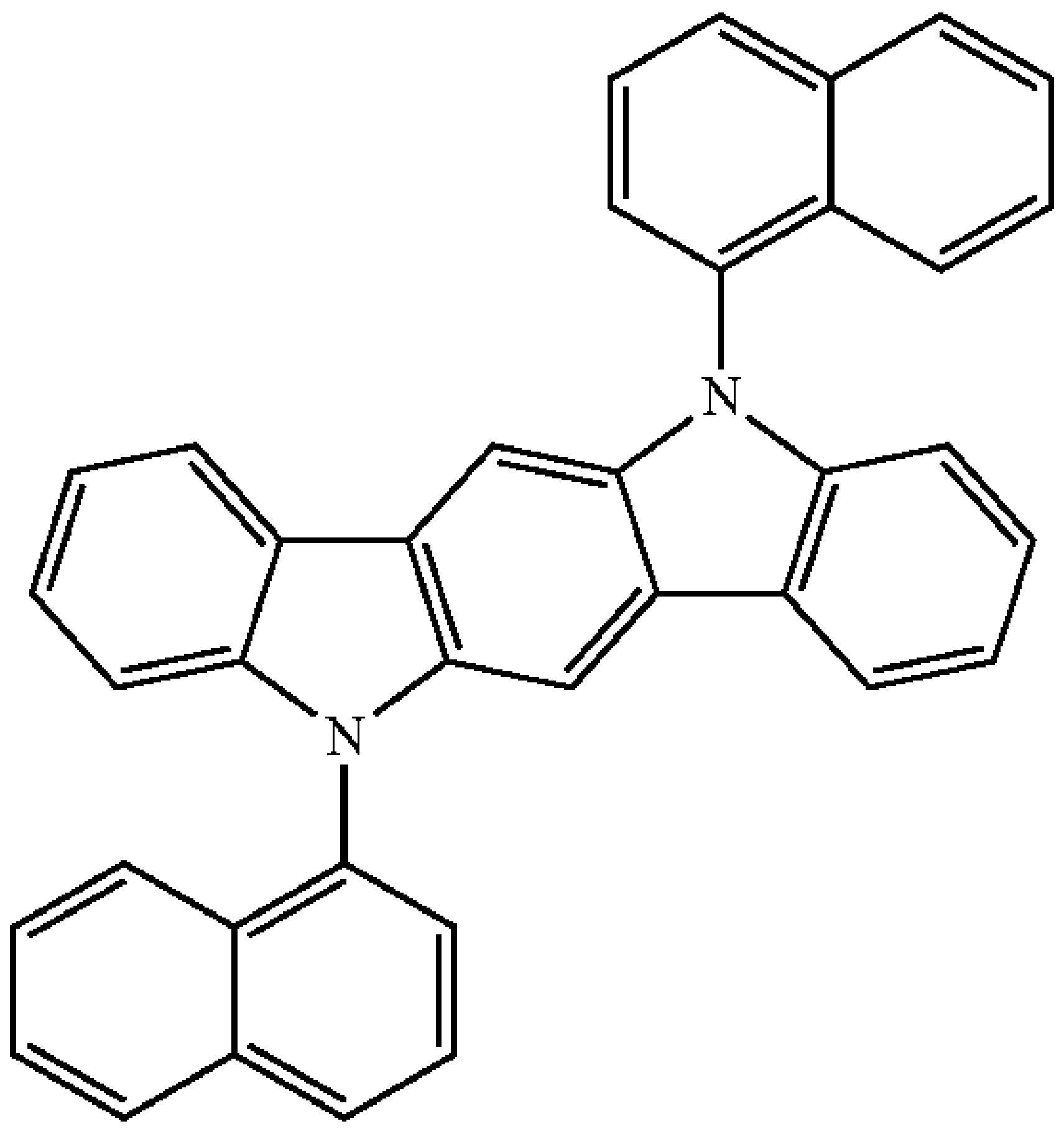
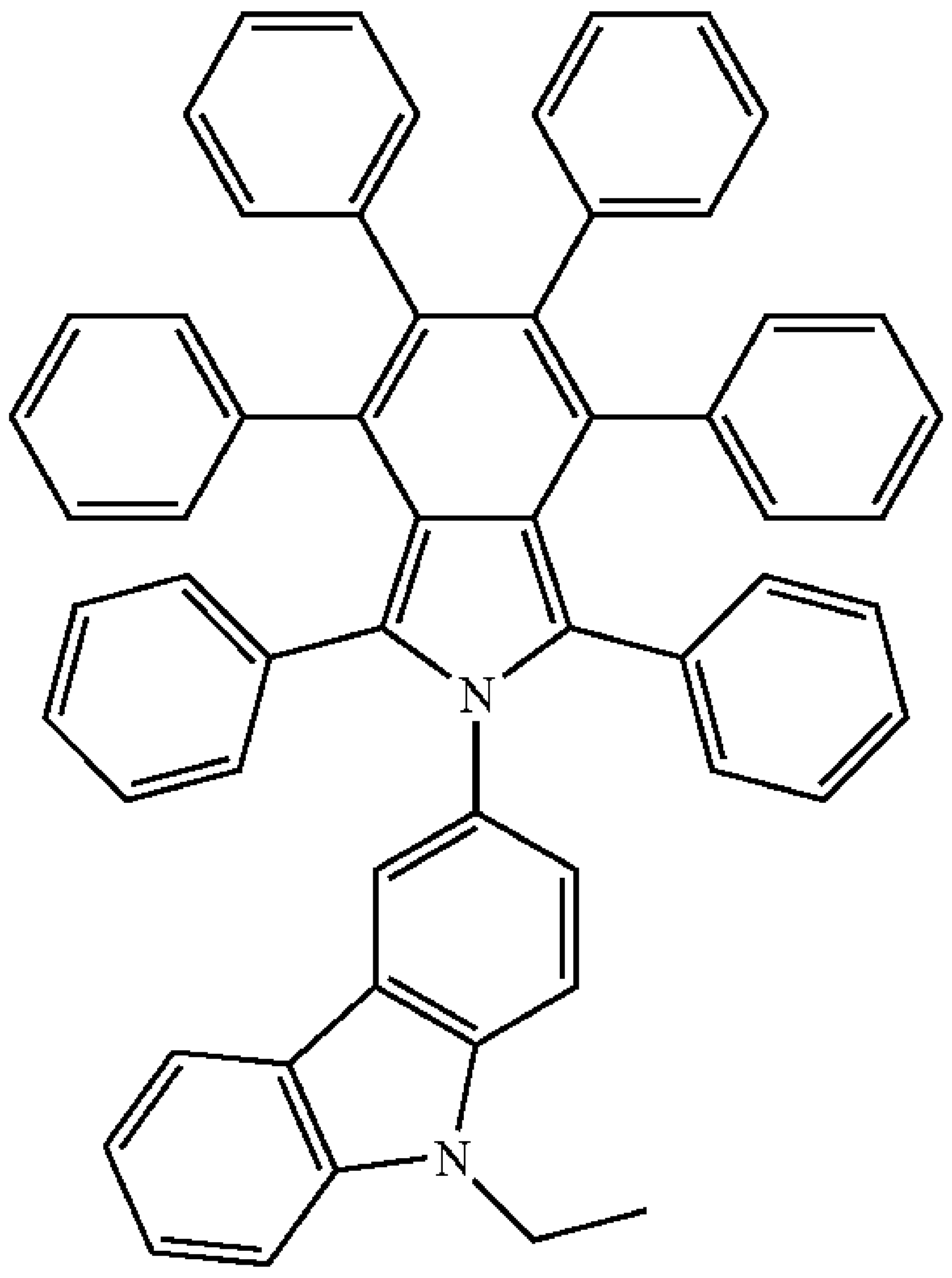
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
Arylamine carbazole compounds		Adv. Mater. 6, 677 (1994), US20080124572
Triarylamine with (di)benzothiophene/ (di)benzofuran		US20070278938, US20080106190 US20110163302
Indolocarbazoles		Synth. Met. 111, 421 (2000)
Isoindole compounds		Chem. Mater. 15, 3148 (2003)

TABLE 4-continued

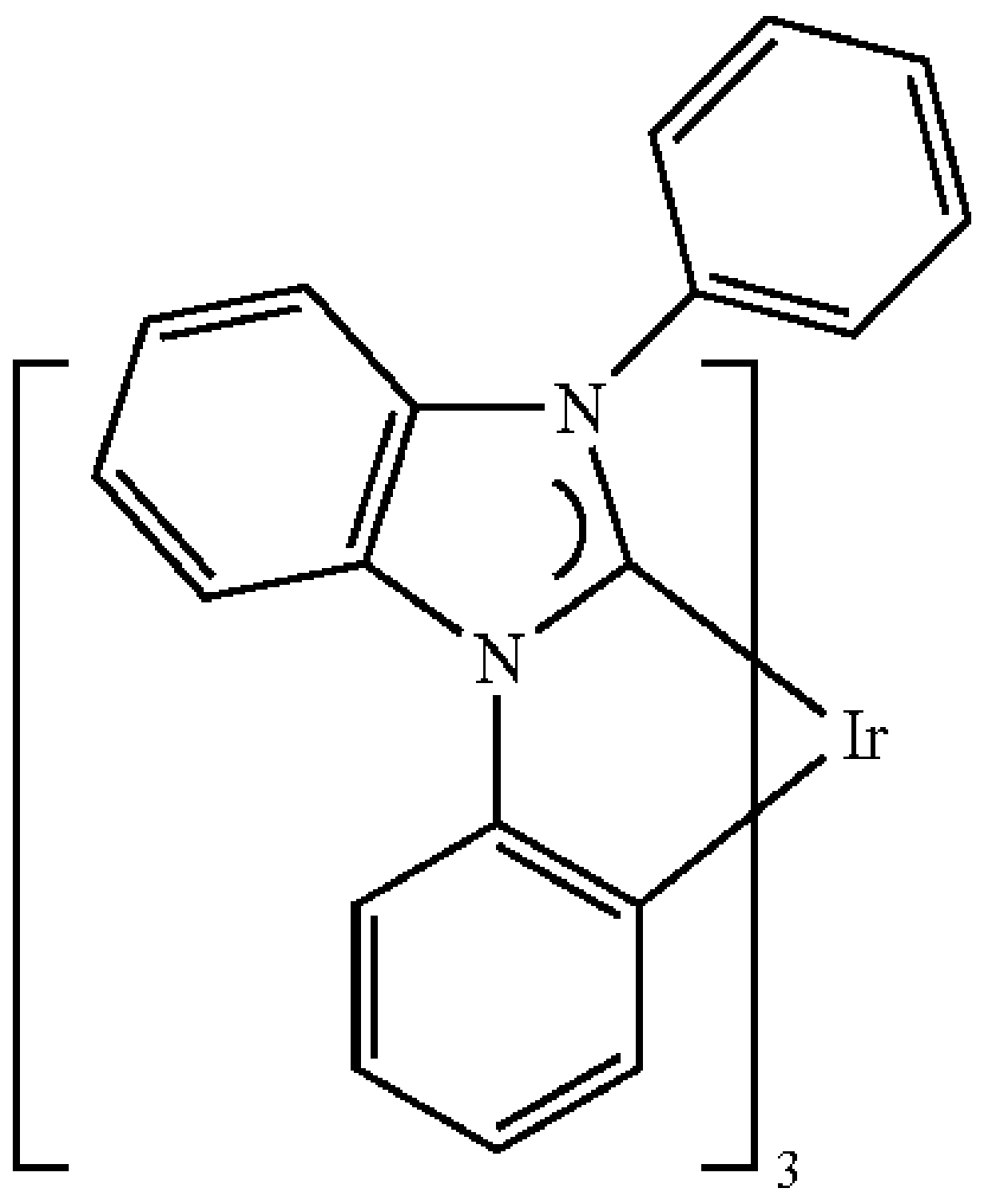
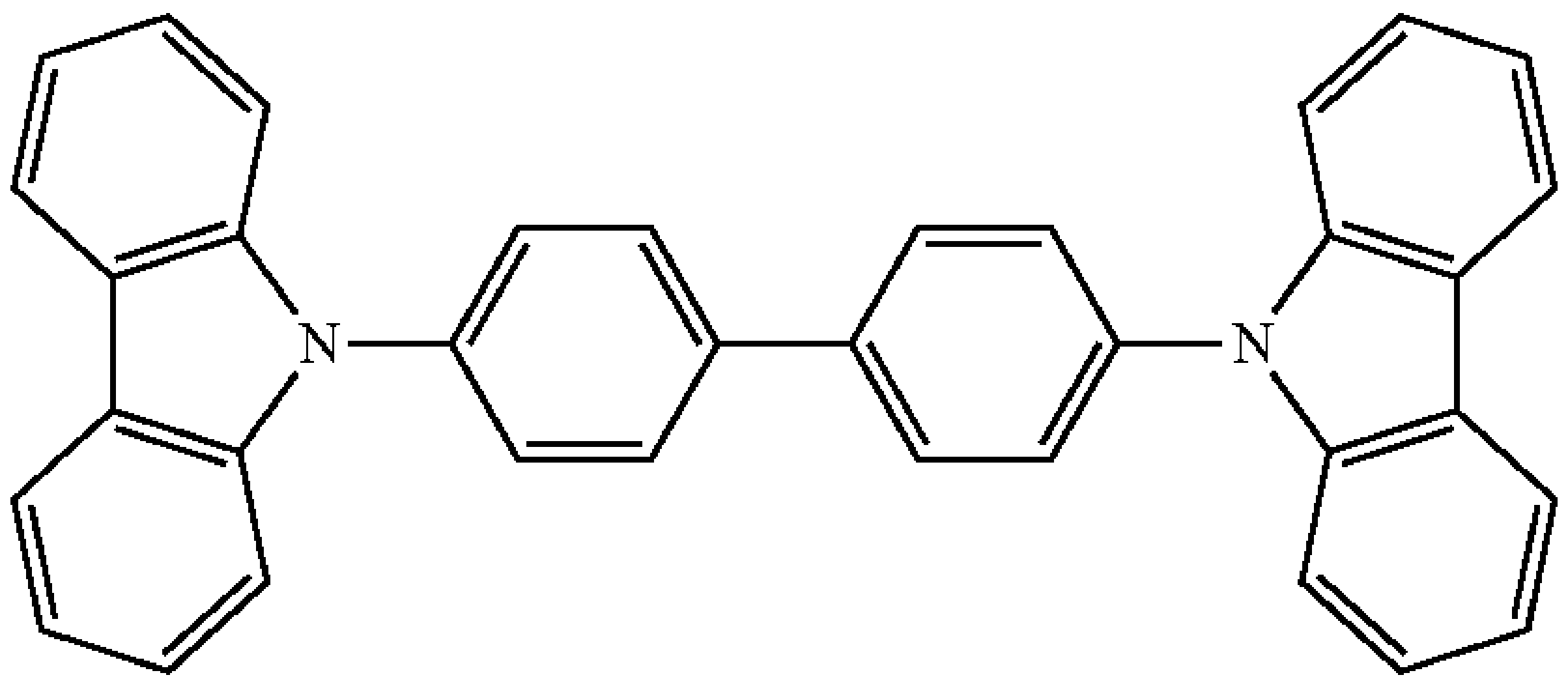
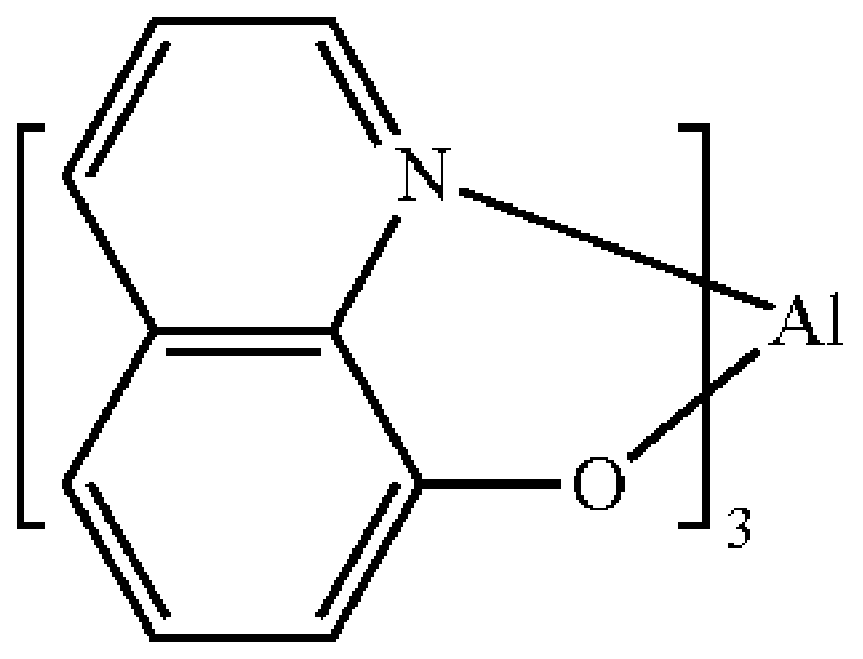
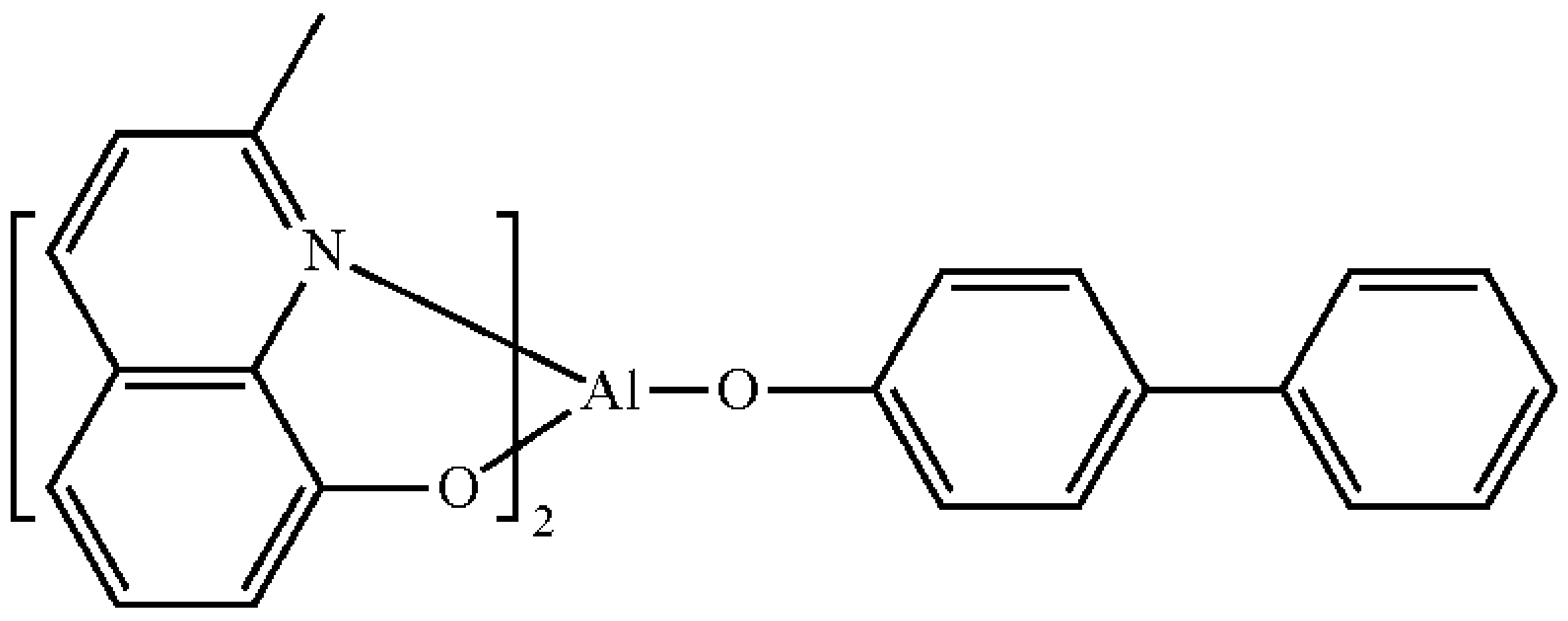
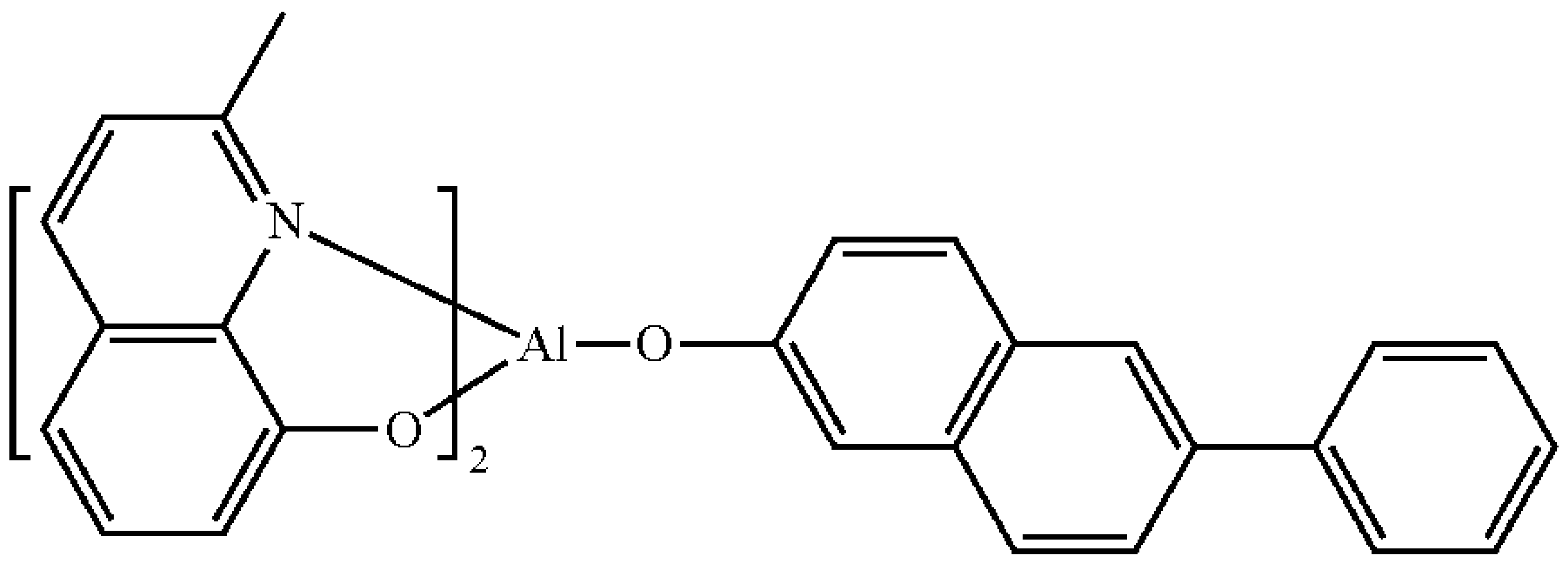
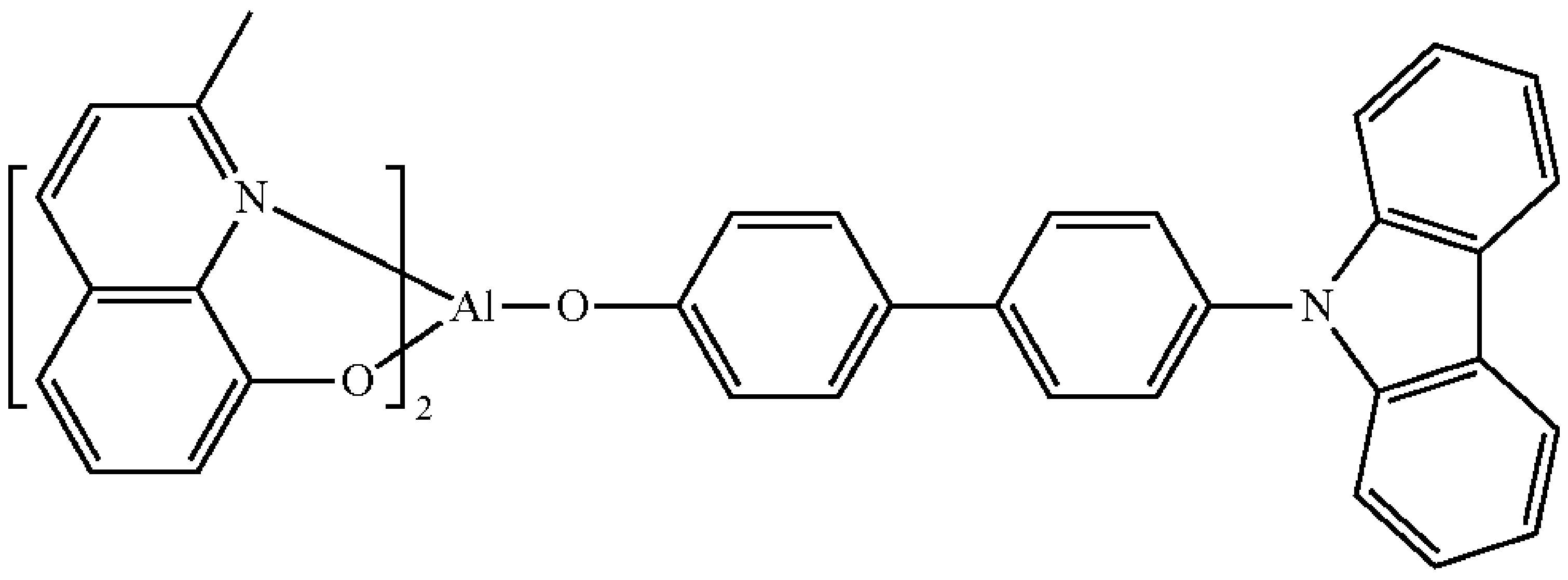
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
Metal carbene complexes		US20080018221
	Phosphorescent OLED host materials Red hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)
Metal 8-hydroxyquinolates (e.g., Alq_3, BAlq)		Nature 395, 151 (1998)
		US20060202194
		WO2005014551
		WO2006072002

TABLE 4-continued

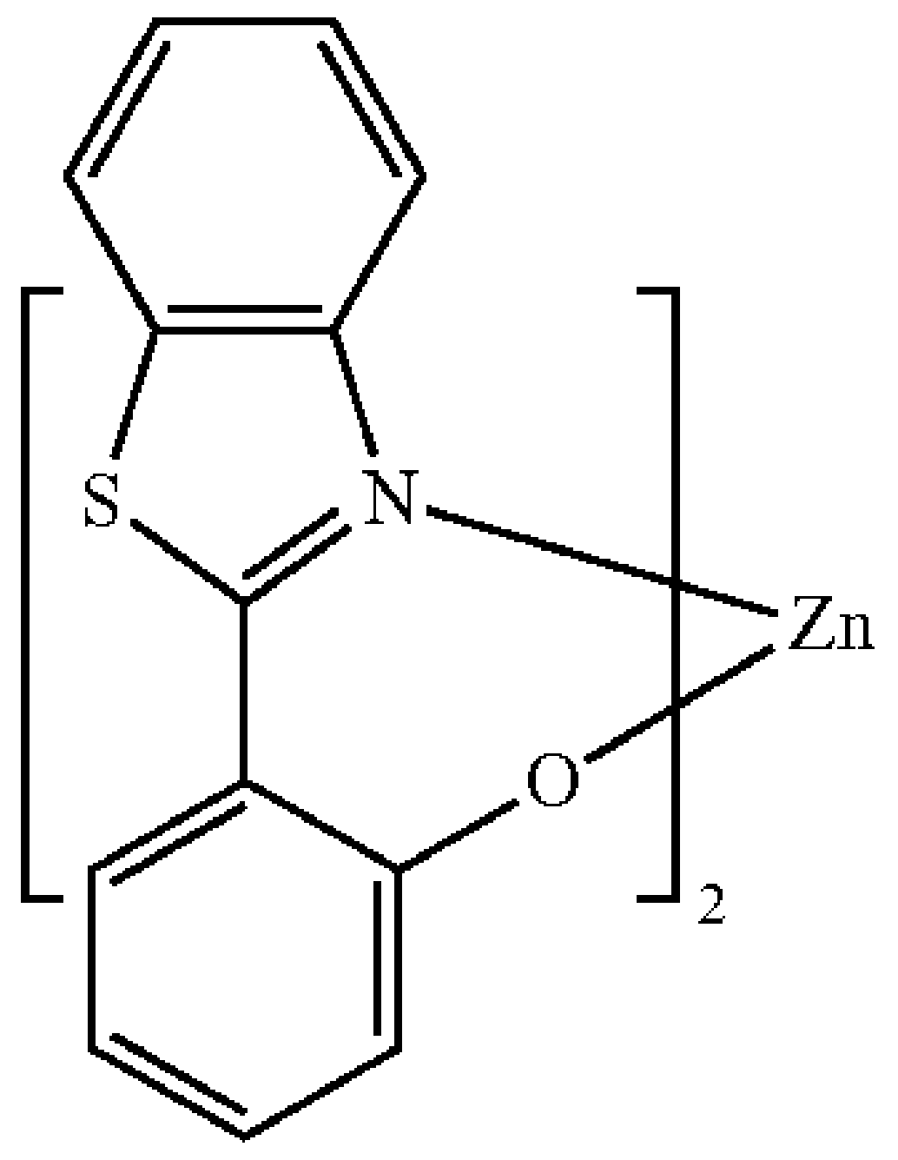
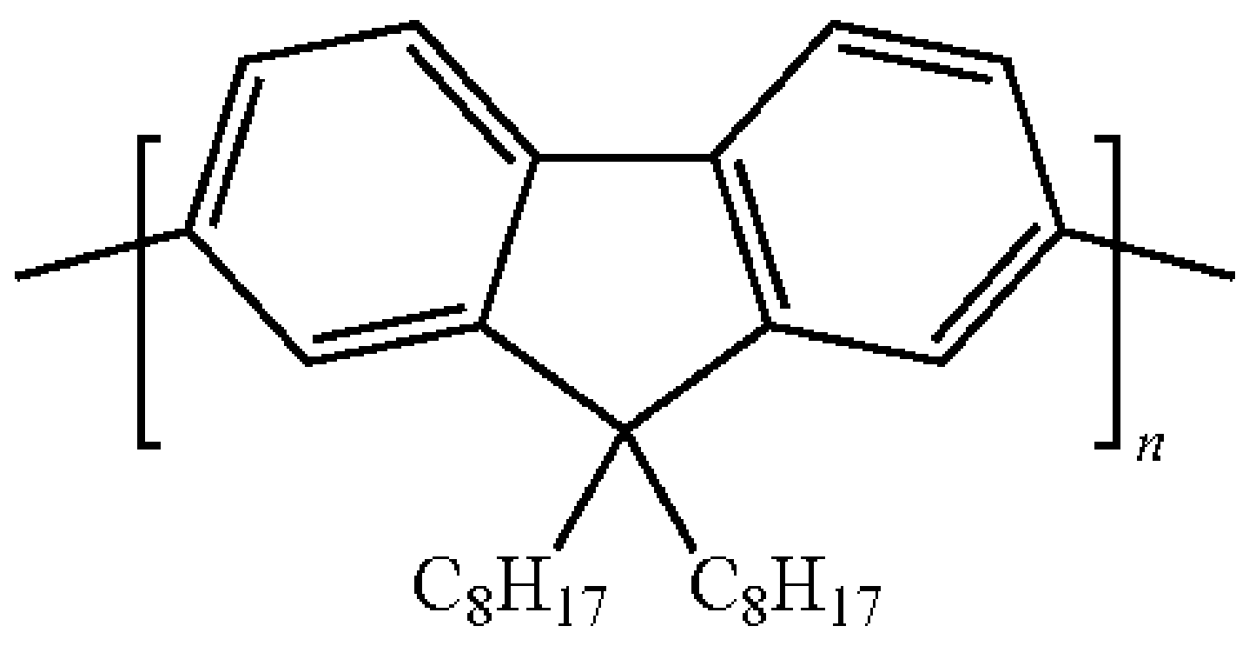
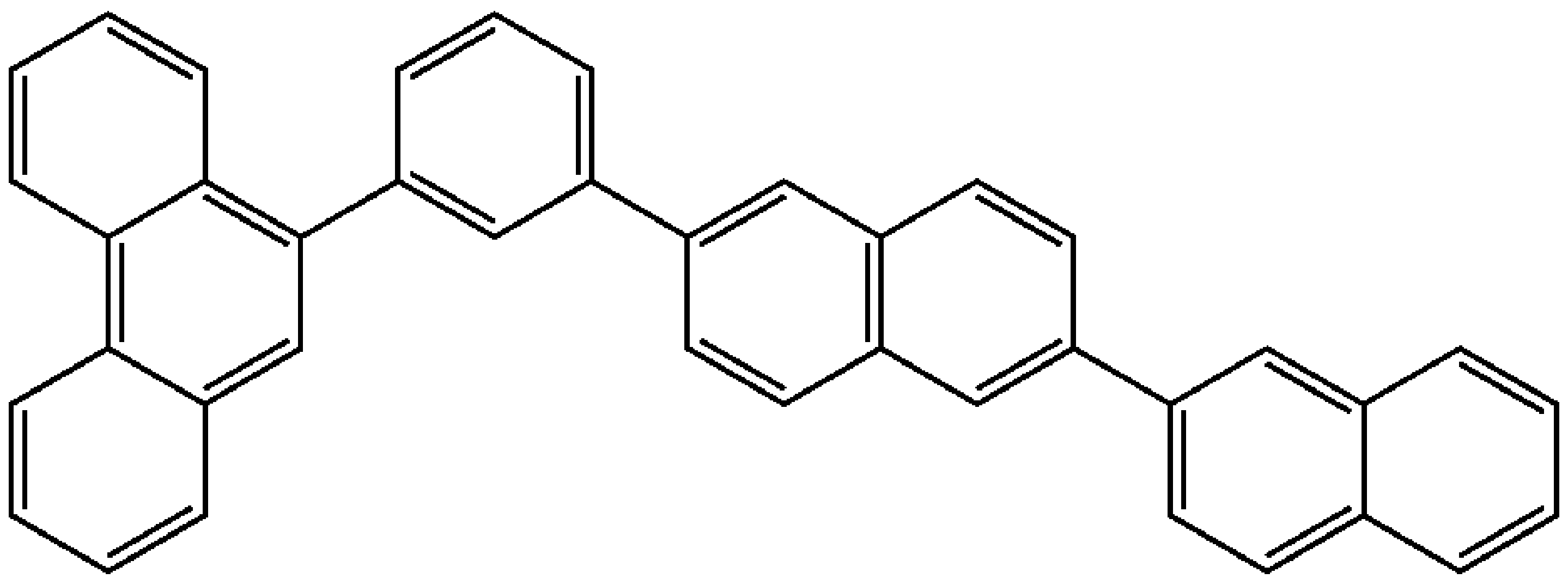
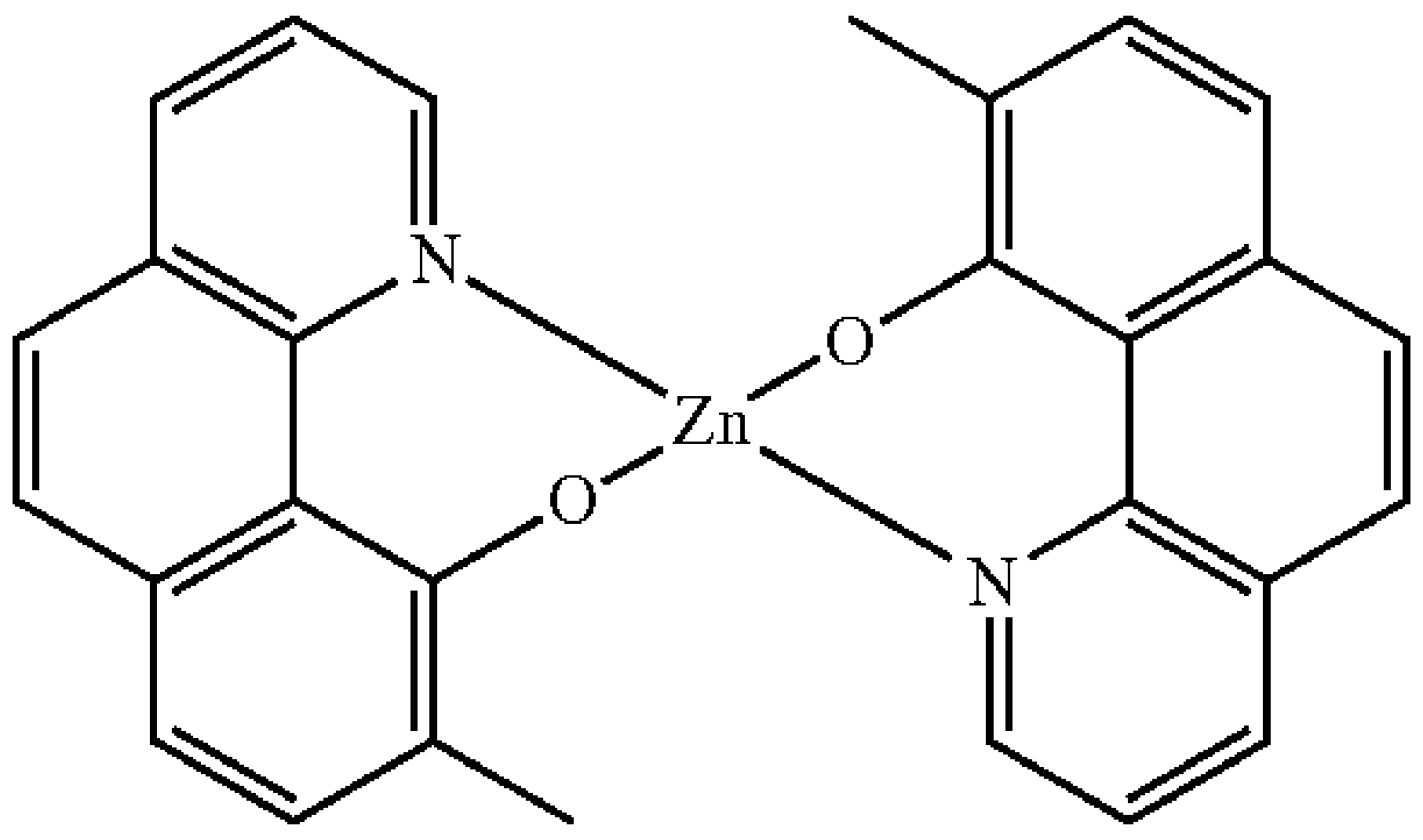
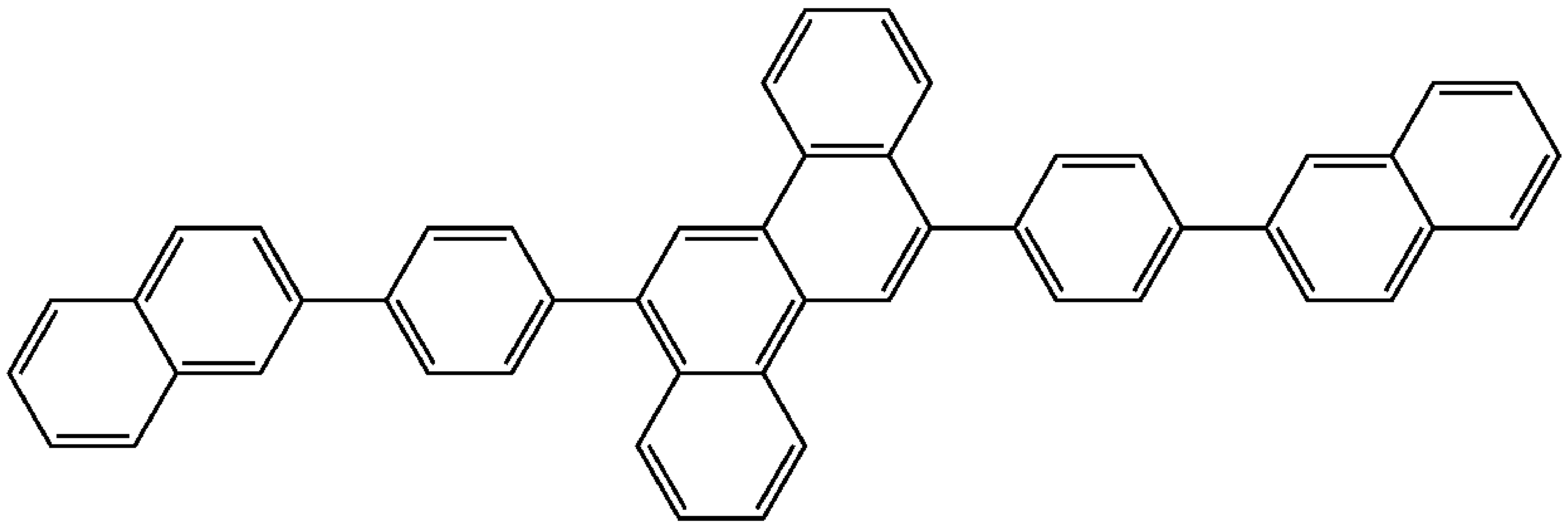
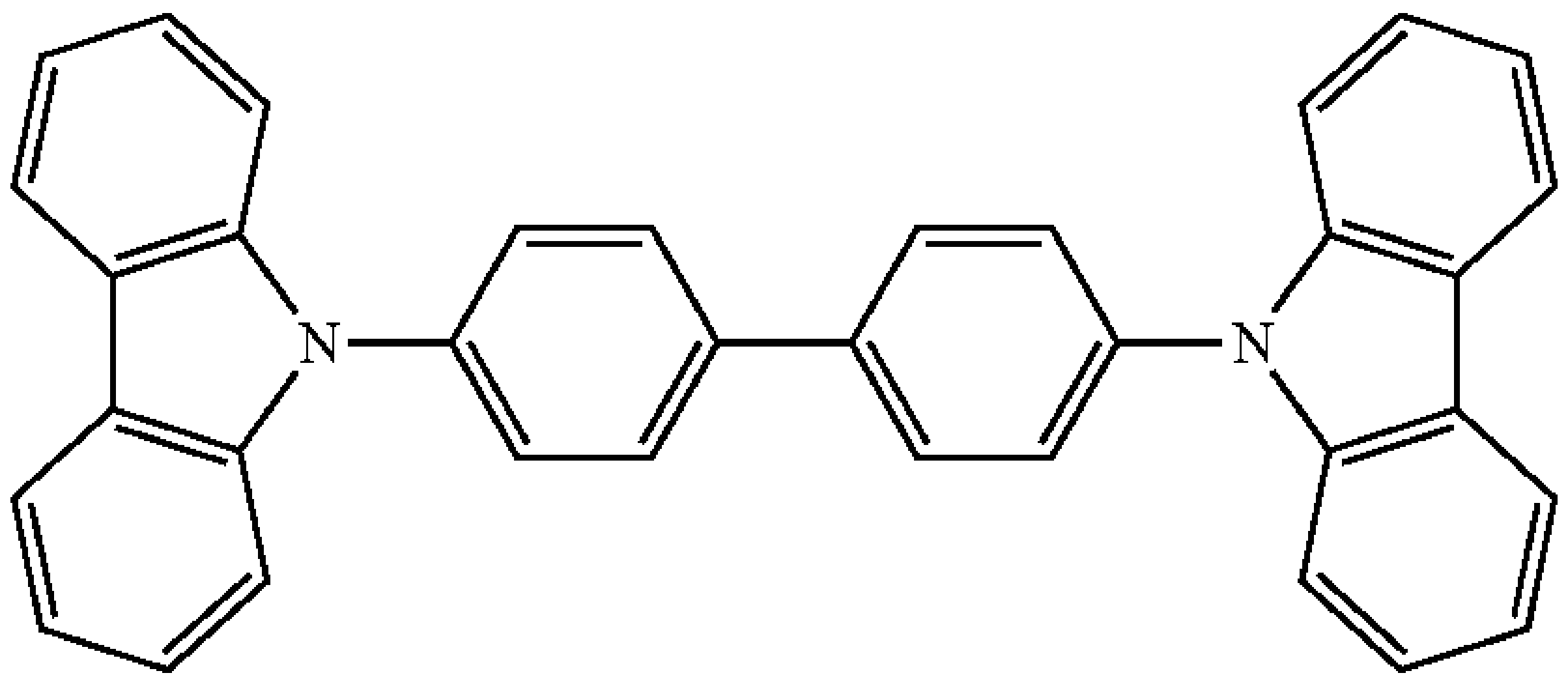
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Metal phenoxy-benzothiazole compounds		Appl. Phys. Lett. 90, 123509 (2007)
Conjugated oligomers and polymers (e.g., polyfluorene)		Org. Electron. 1, 15 (2000)
Aromatic fused rings		WO2009066779, WO2009066778, WO2009063833, US20090045731, US20090045730, WO2009008311, US20090008605, US20090009065
Zinc complexes		WO2010056066
Chrysene based compounds		WO2011086863
	Green hosts	
Arylcarbazoles		Appl. Phys. Lett. 78, 1622 (2001)

TABLE 4-continued

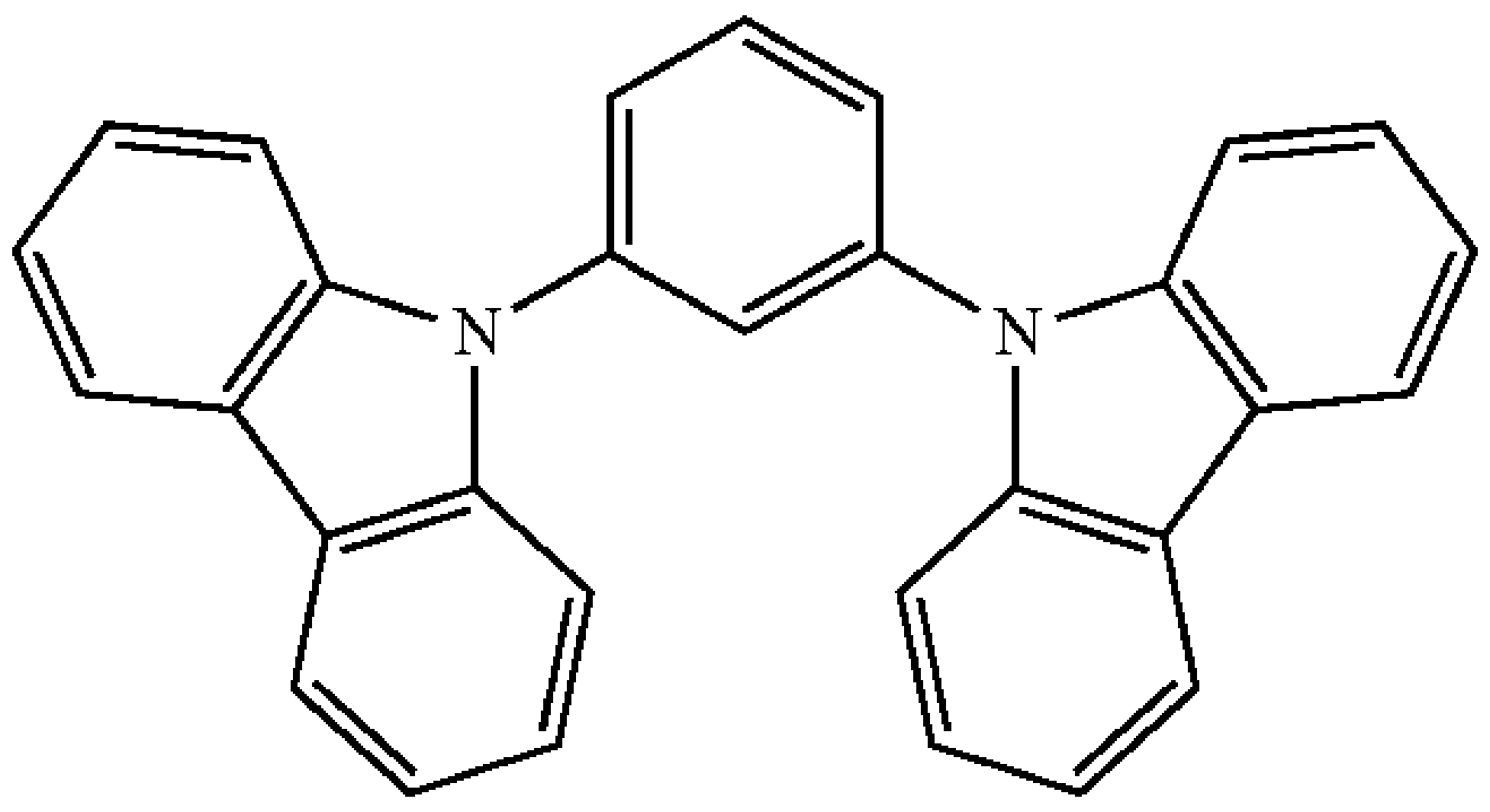
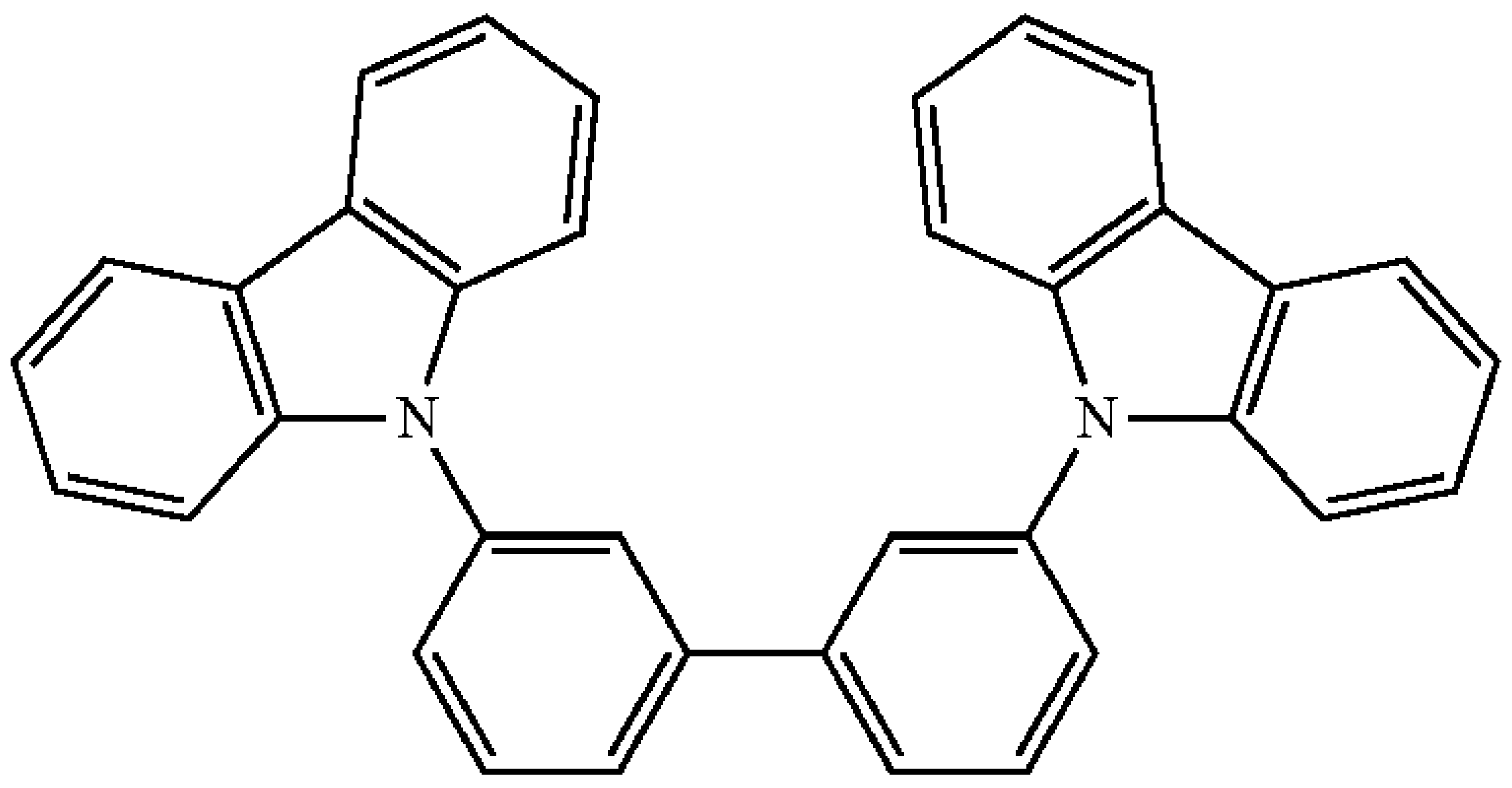
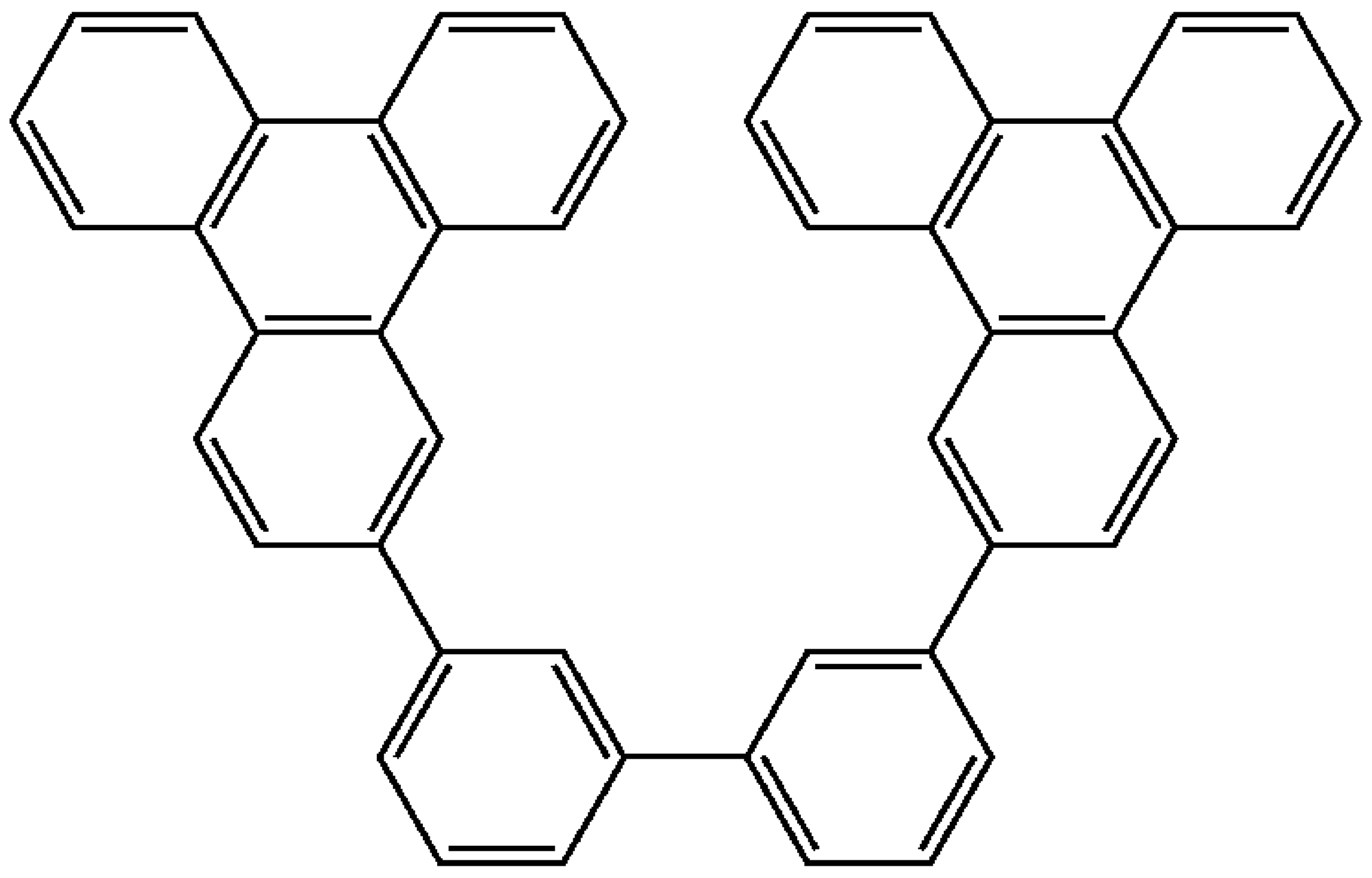
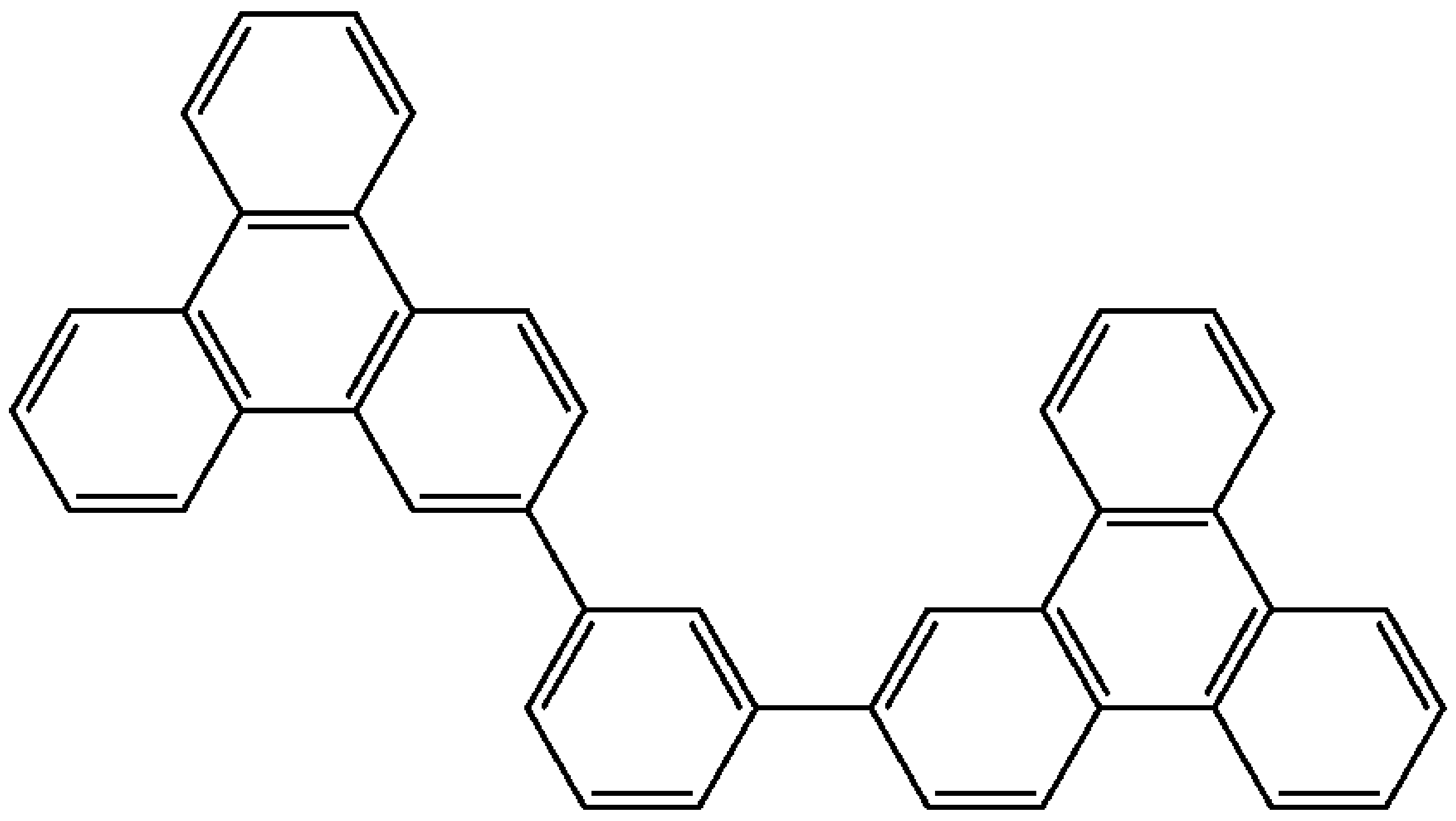
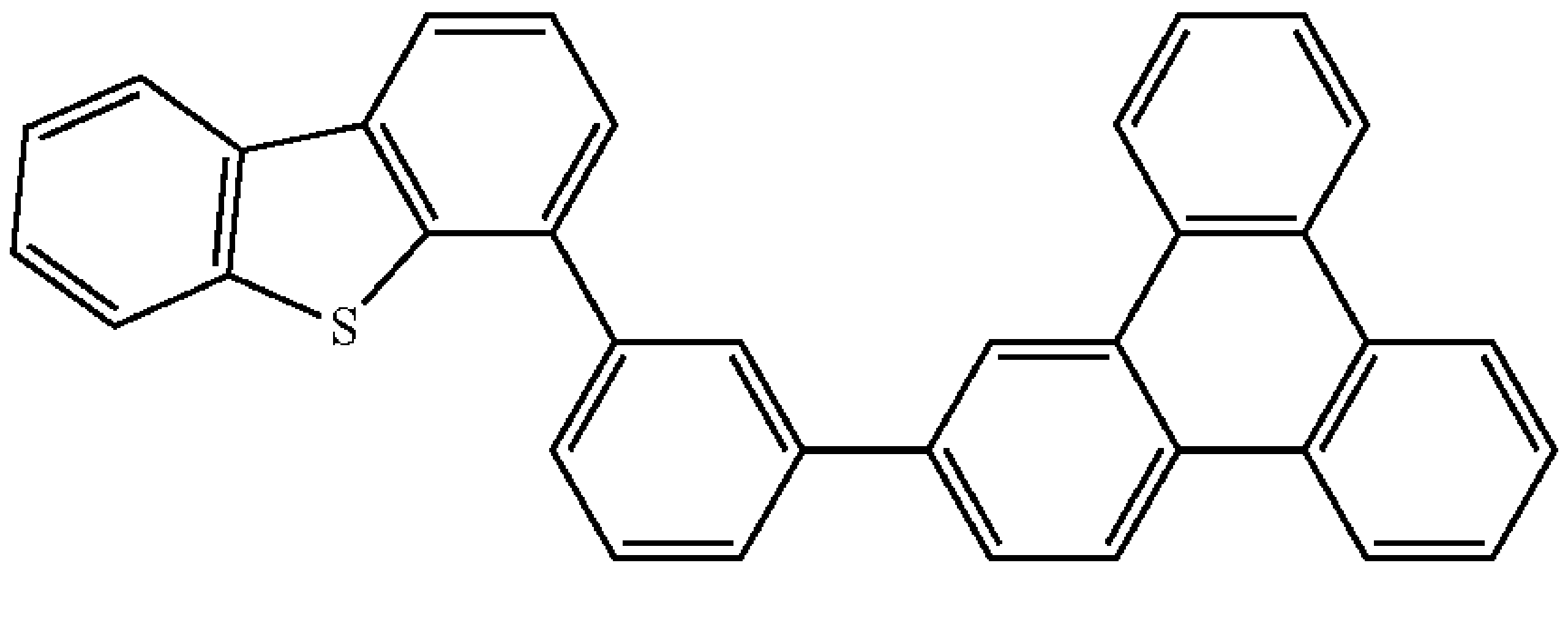
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		US20030175553
		WO2001039234
Aryltriphenylene compounds		US20060280965
		US20060280965
		WO2009021126

TABLE 4-continued

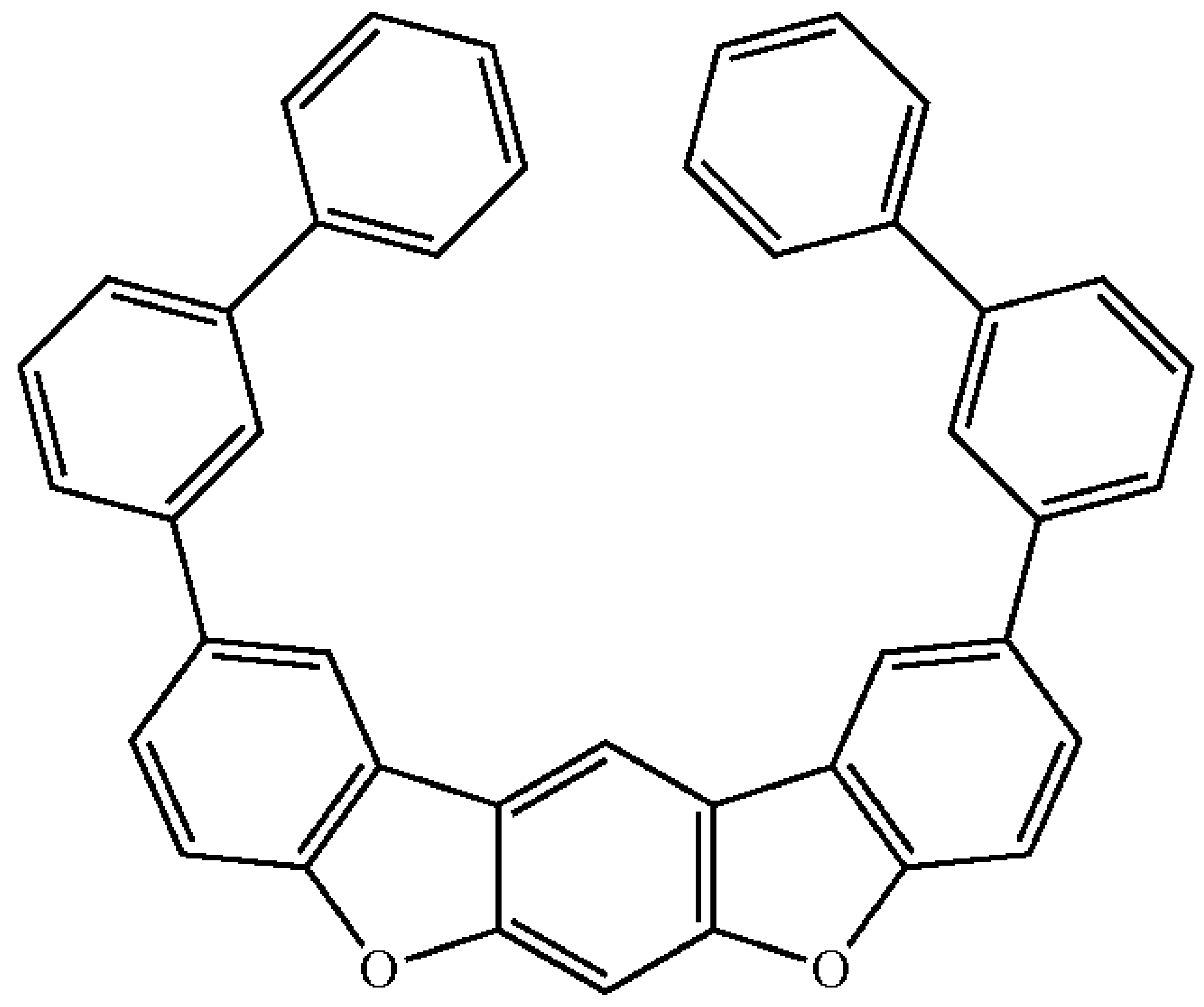
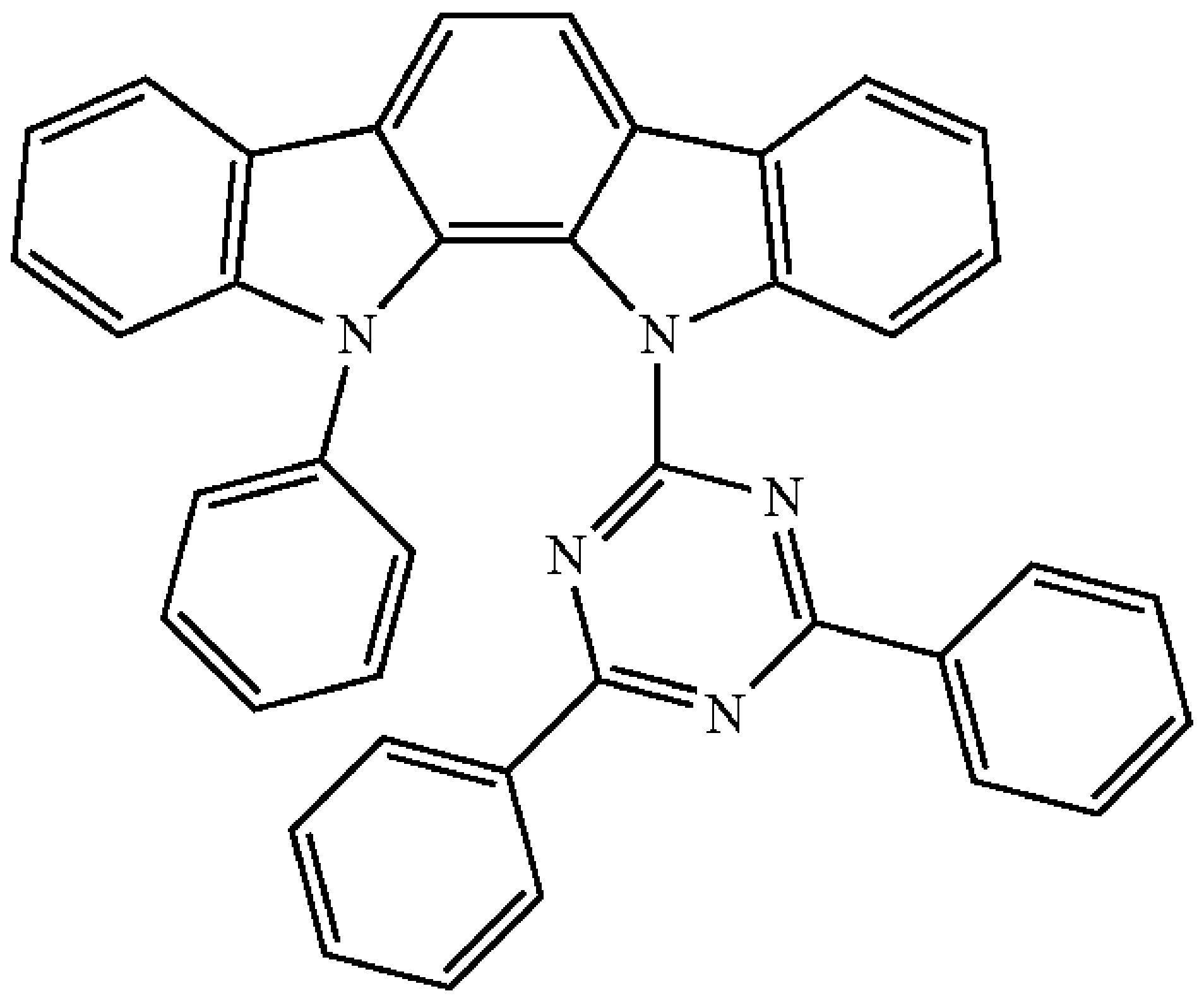
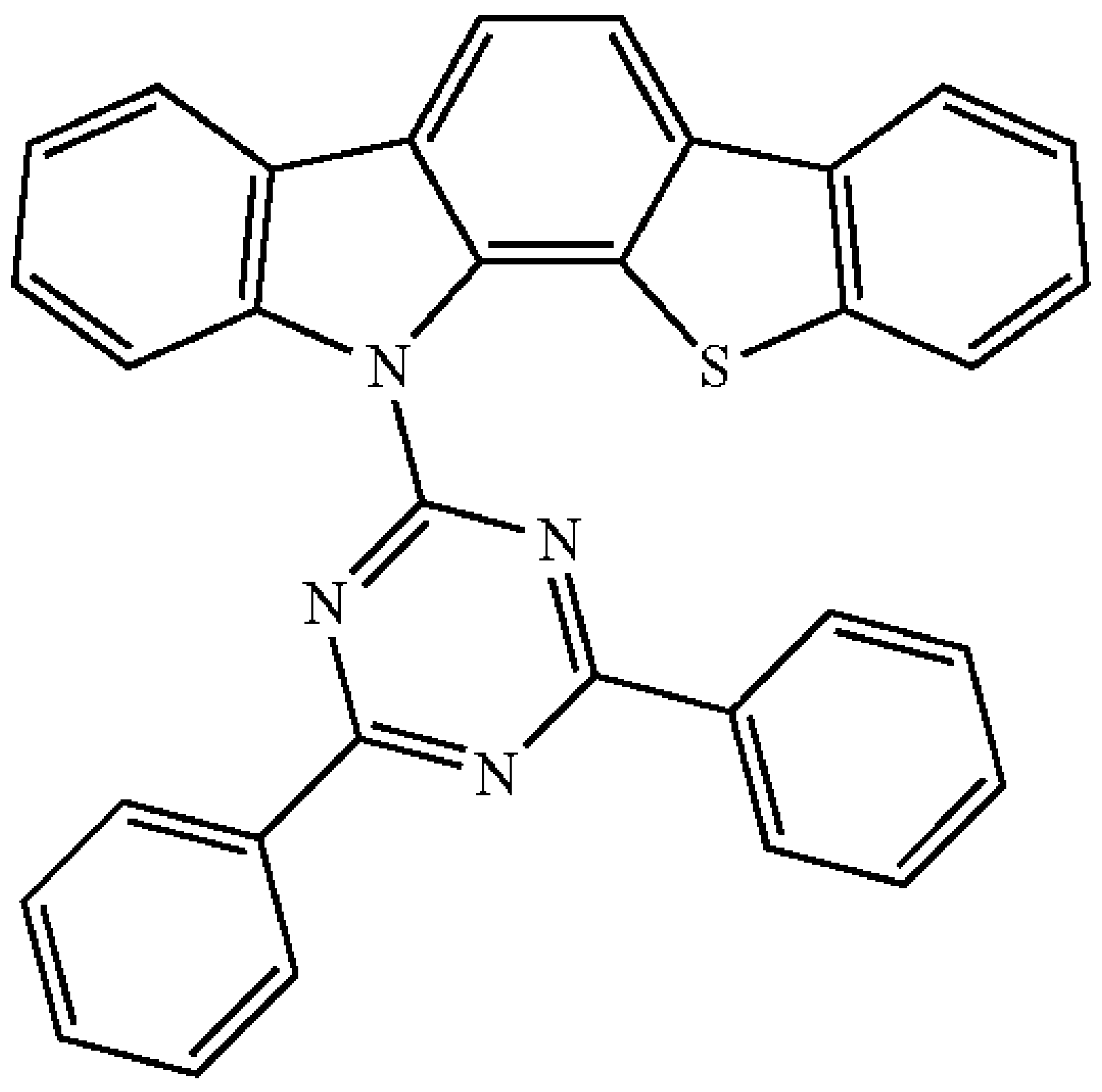
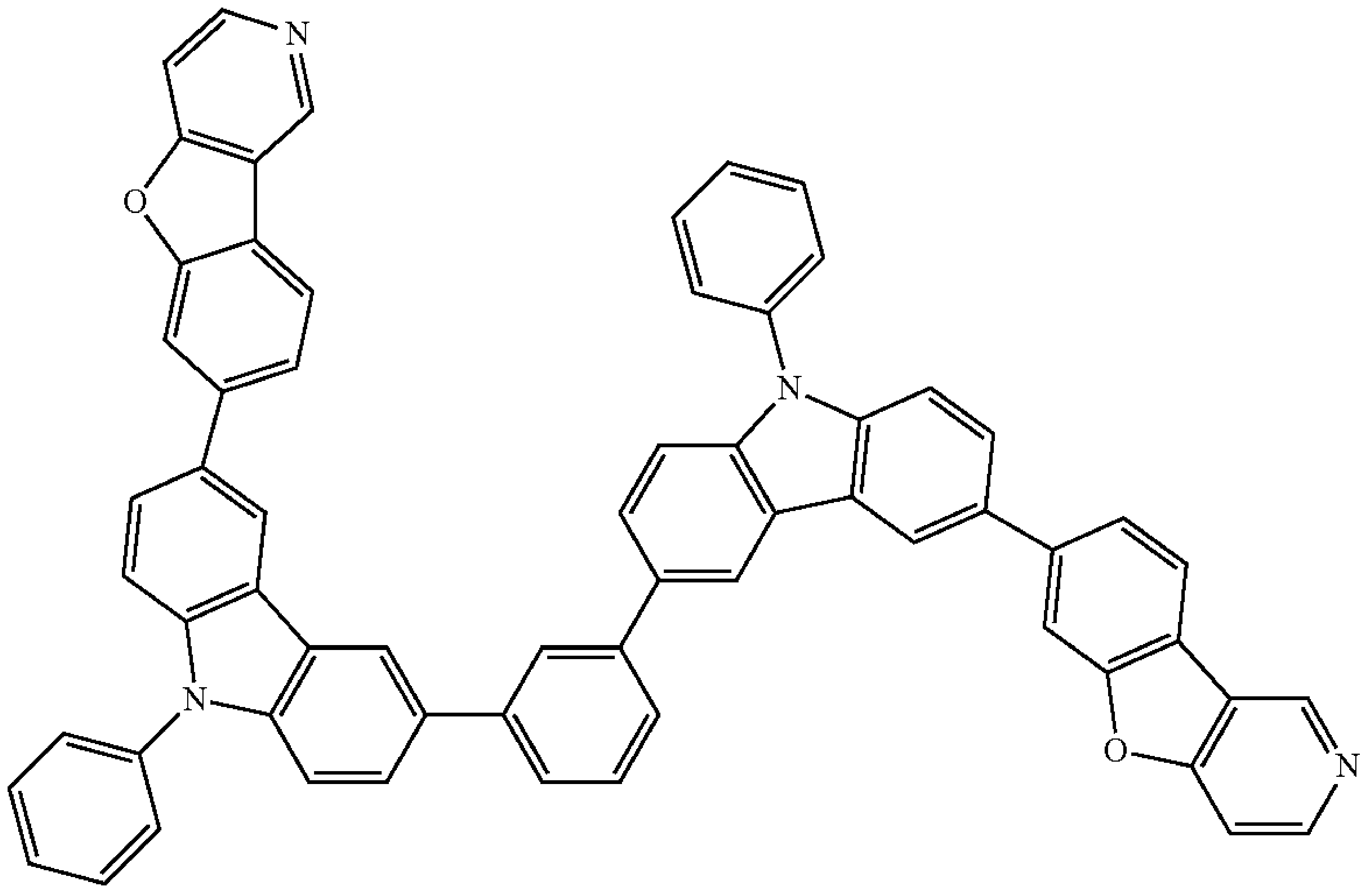
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
Poly-fused heteroaryl compounds		US20090309488 US20090302743 US20100012931
Donor acceptor type molecules		WO2008056746
		WO2010107244
Aza-carbazole/DBT/DBF		JP2008074939

TABLE 4-continued

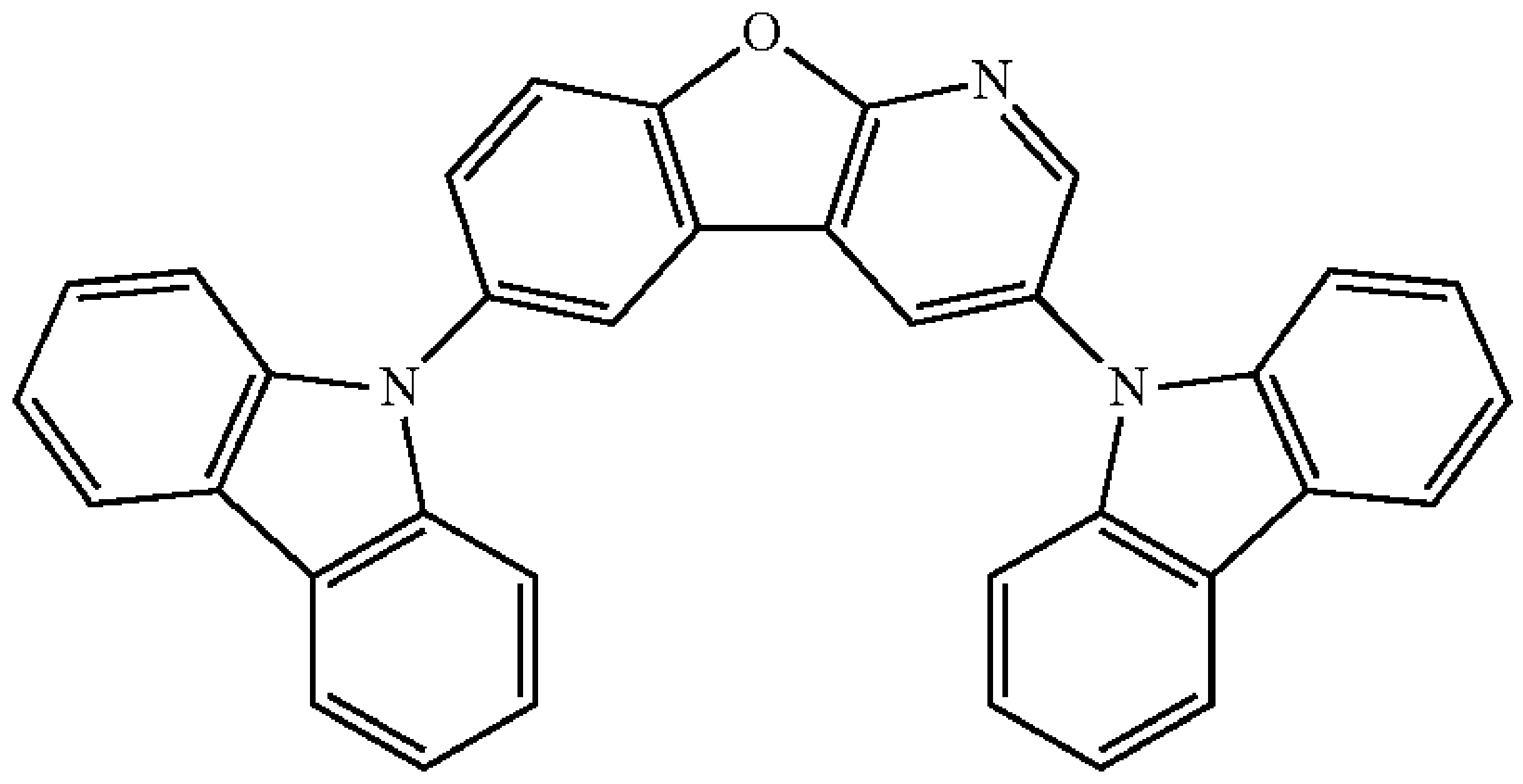
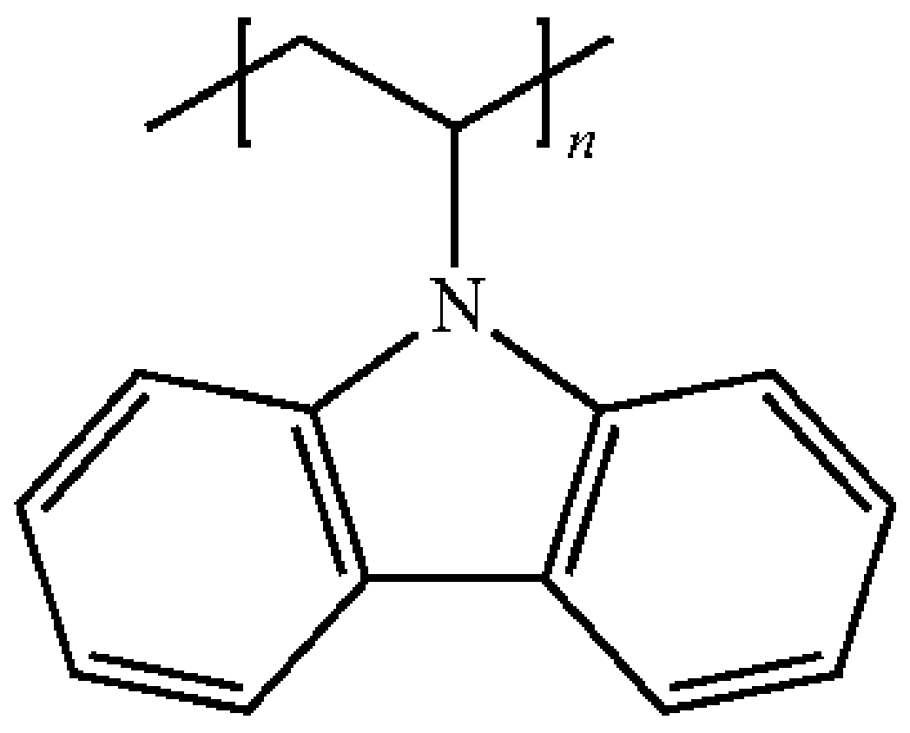
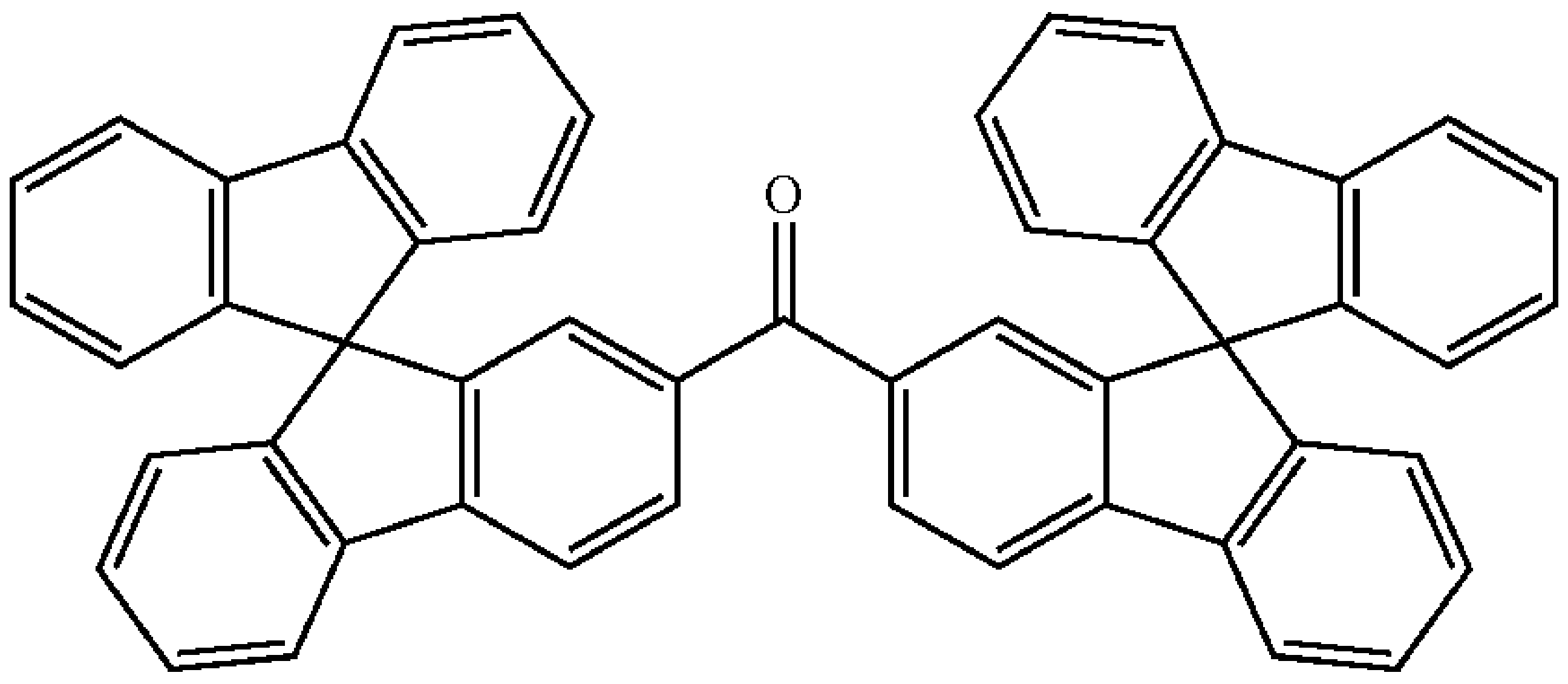
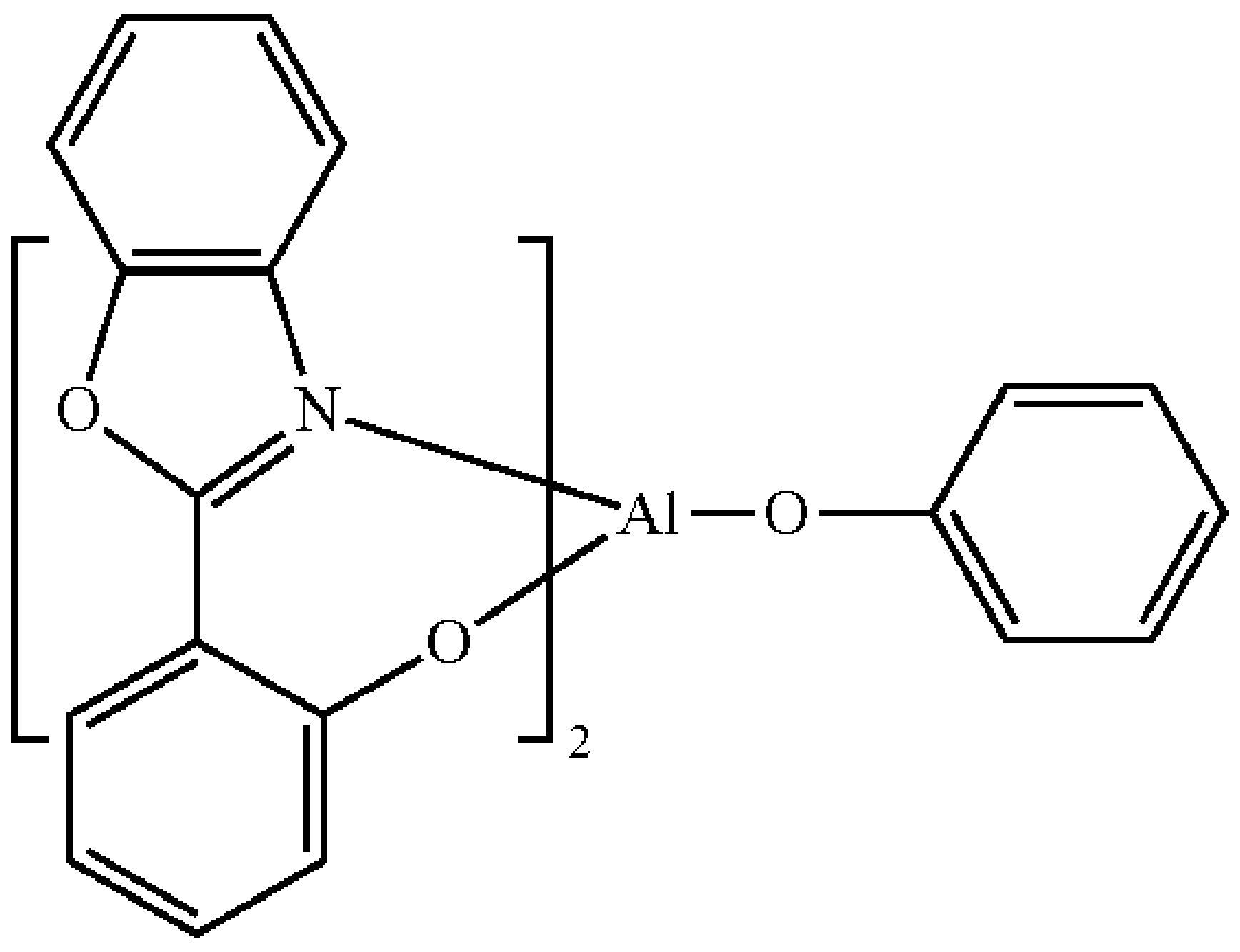
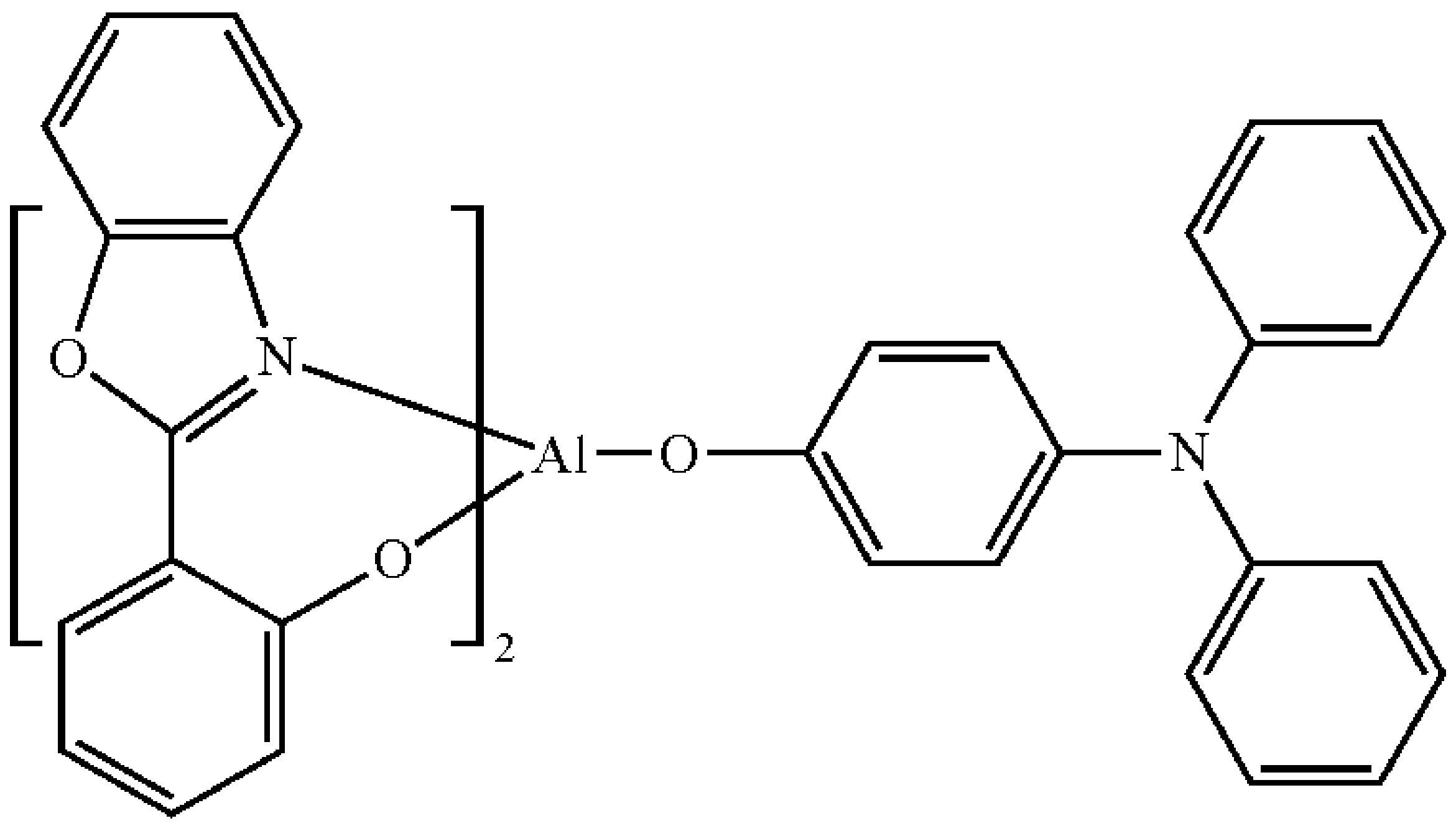
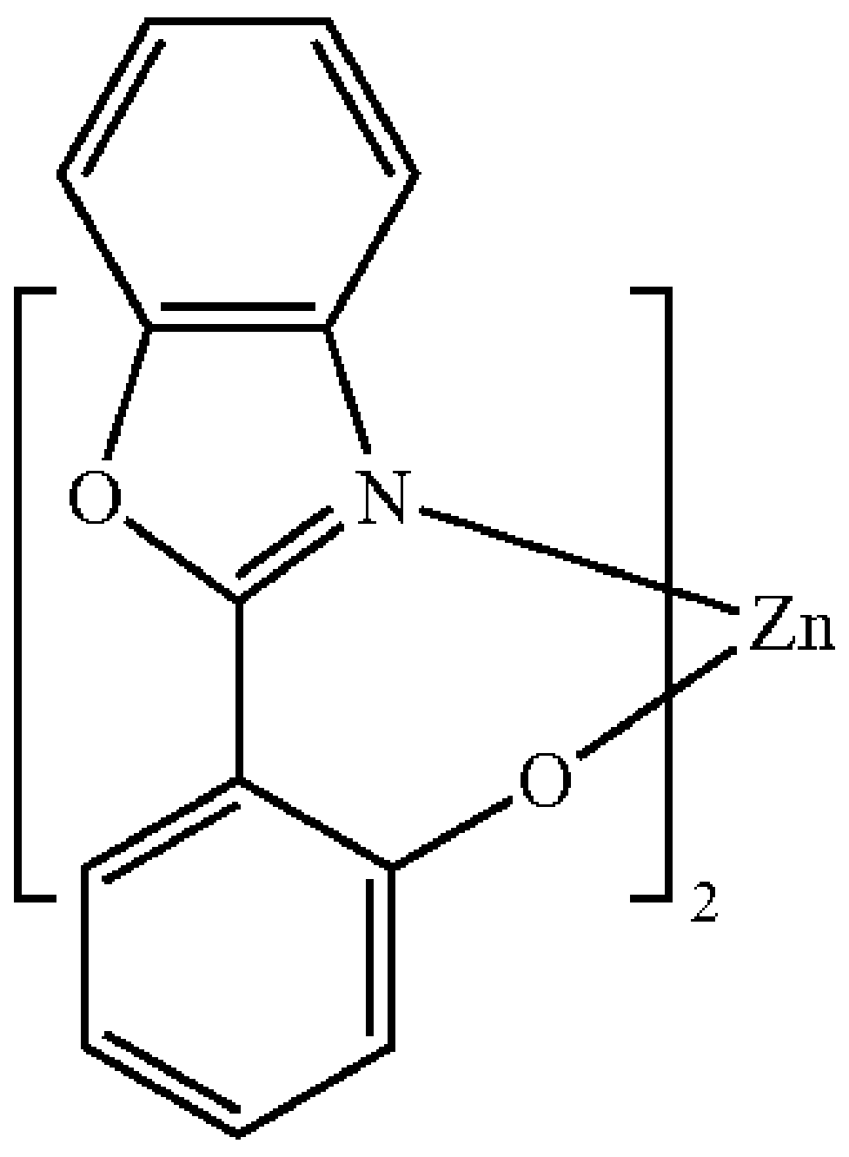
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		US20100187984
Polymers (e.g., PVK)		Appl. Phys. Lett. 77, 2280 (2000)
Spirofluorene compounds		WO2004093207
Metal phenoxy-benzooxazole compounds		WO2005089025
		WO2006132173
		JP200511610

TABLE 4-continued

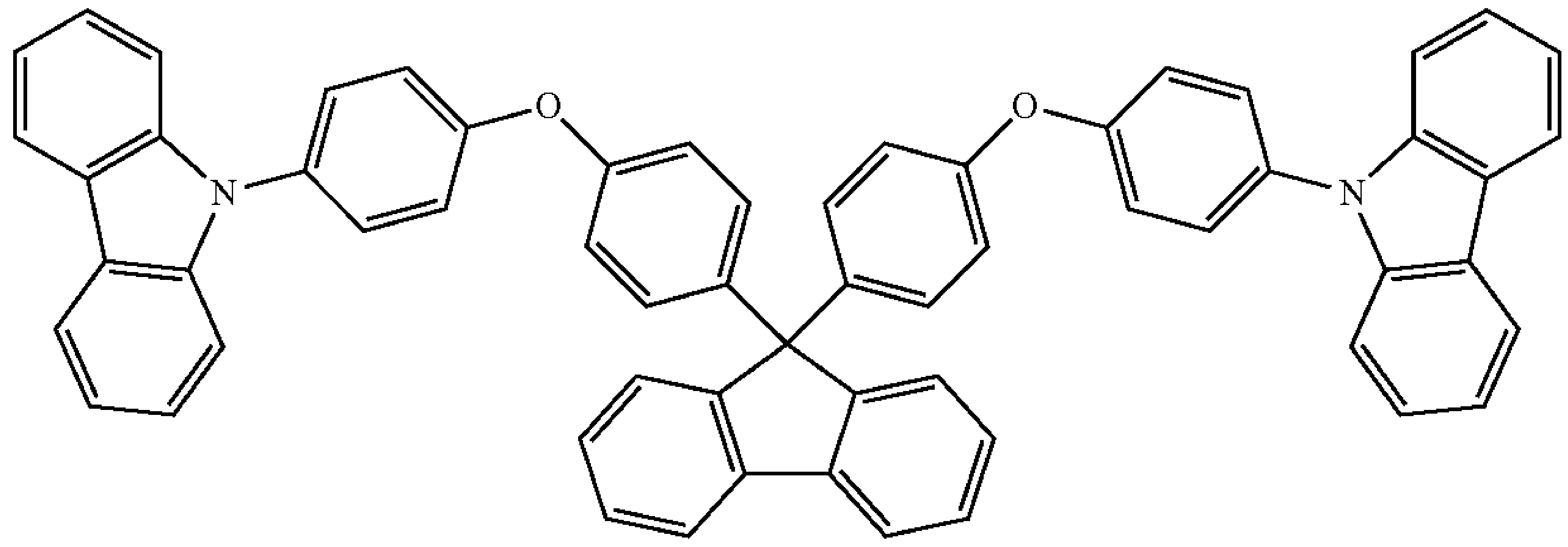
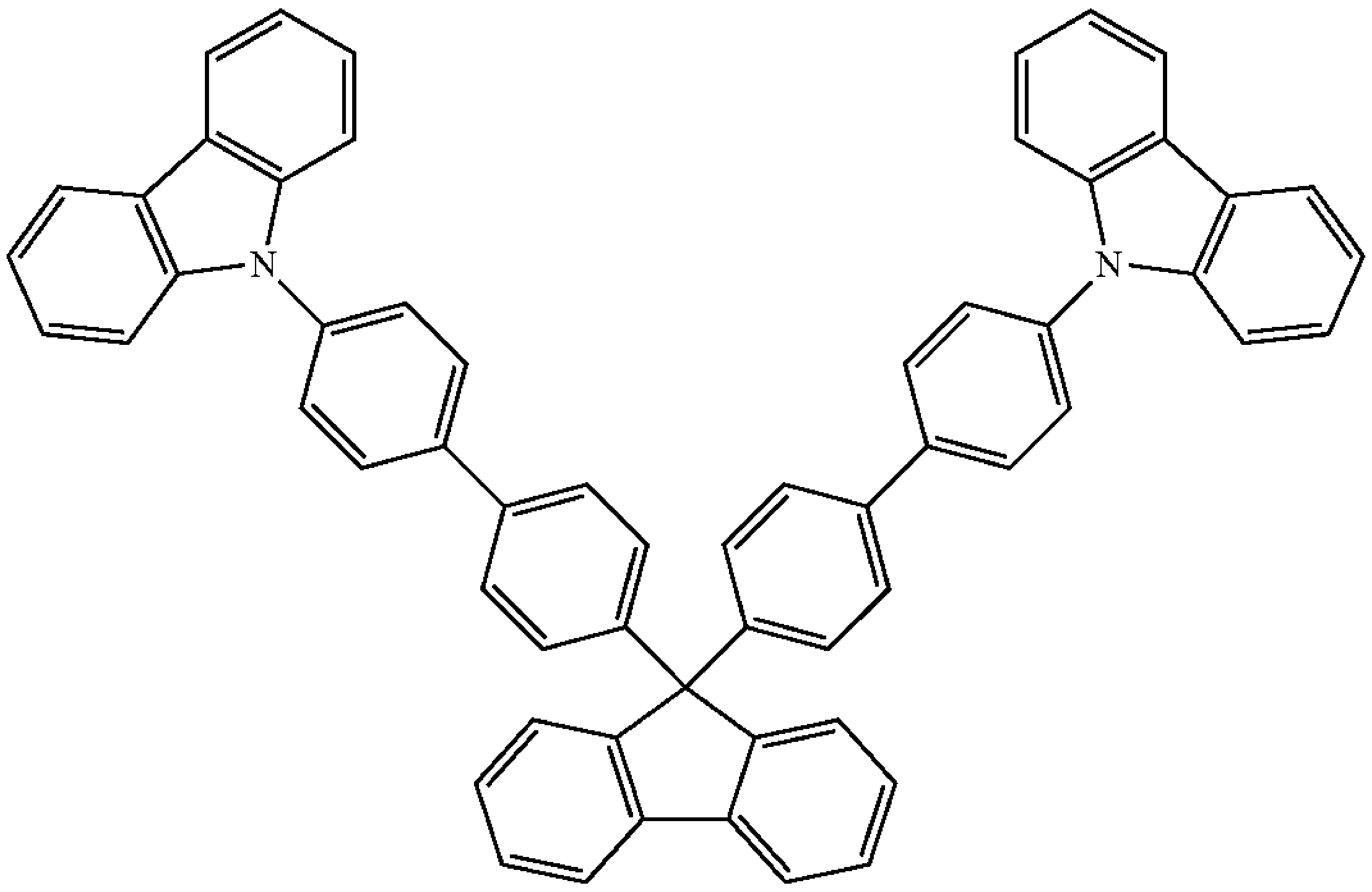
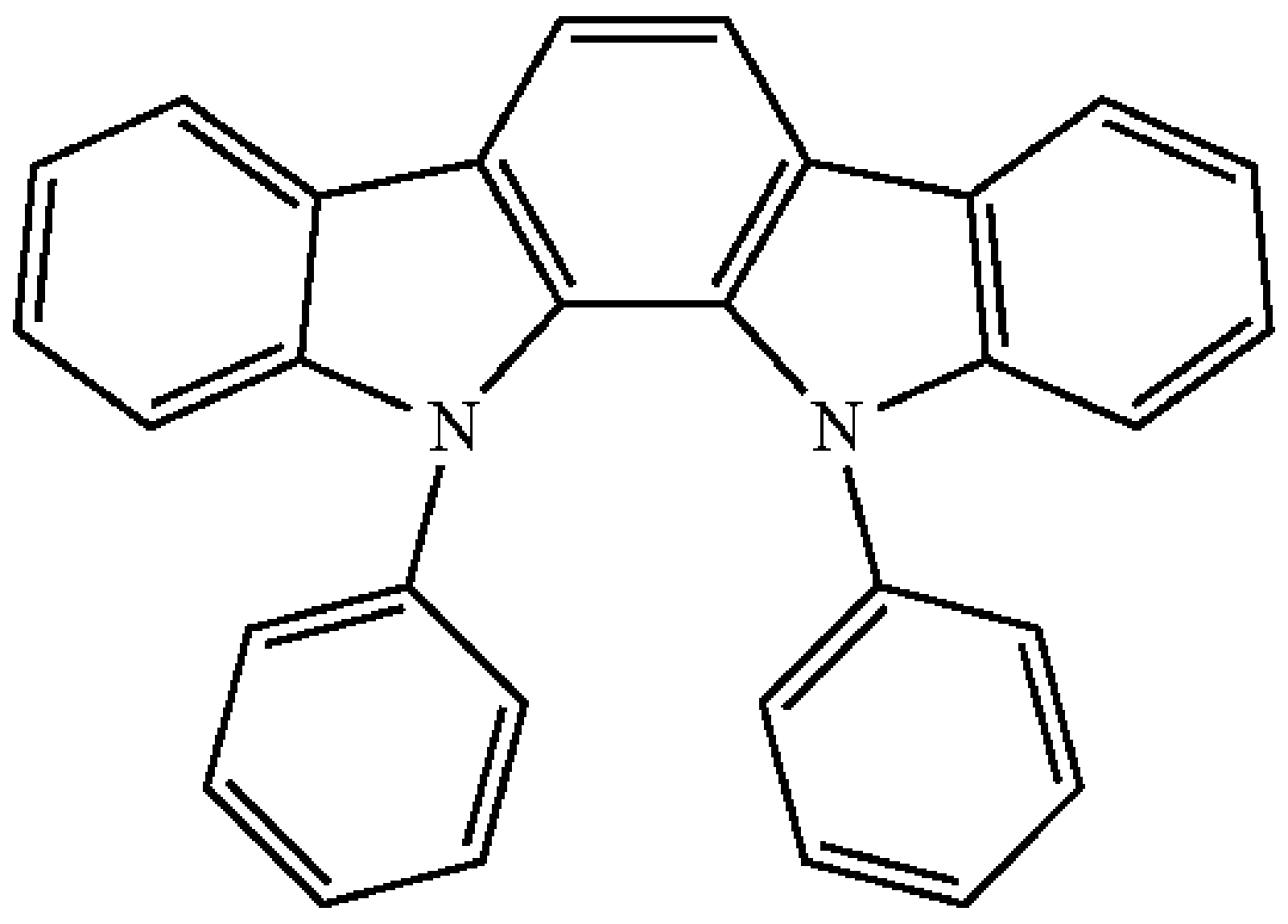
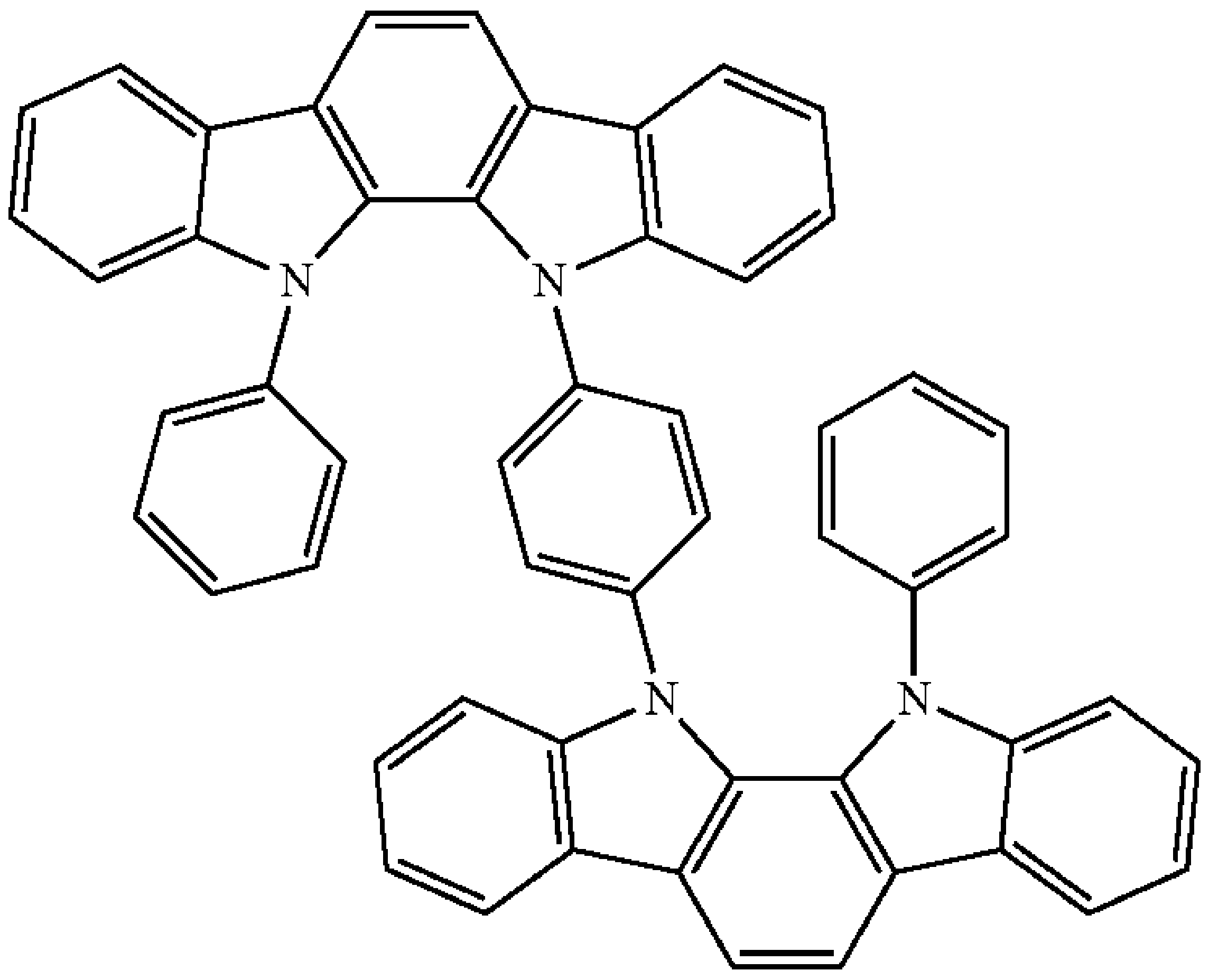
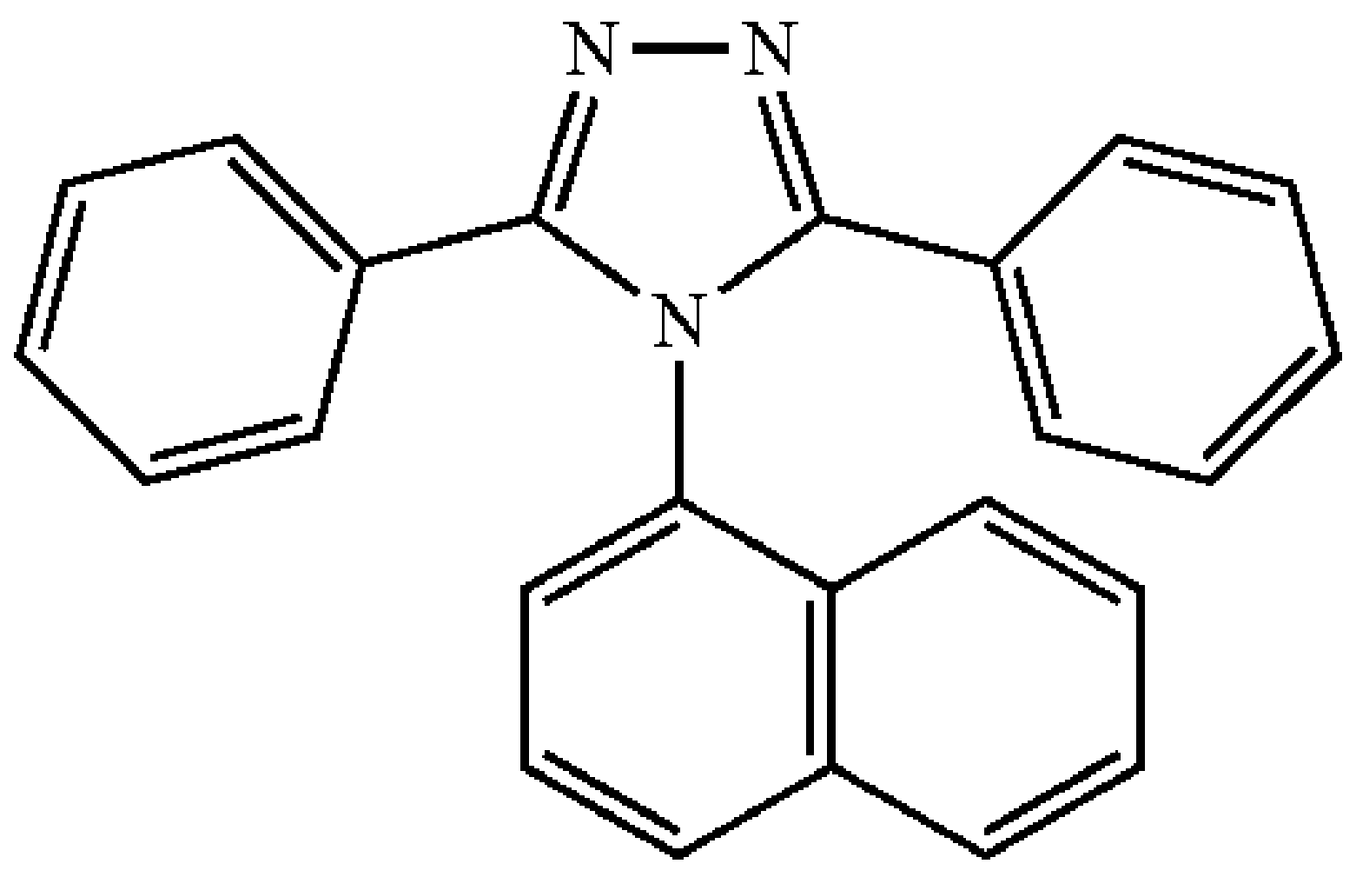
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Spirofluorene-carbazole compounds		JP2007254297
		JP2007254297
Indolocabazoles		WO2007063796
		WO2007063754
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole)		J. Appl. Phys. 90, 5048 (2001)

TABLE 4-continued

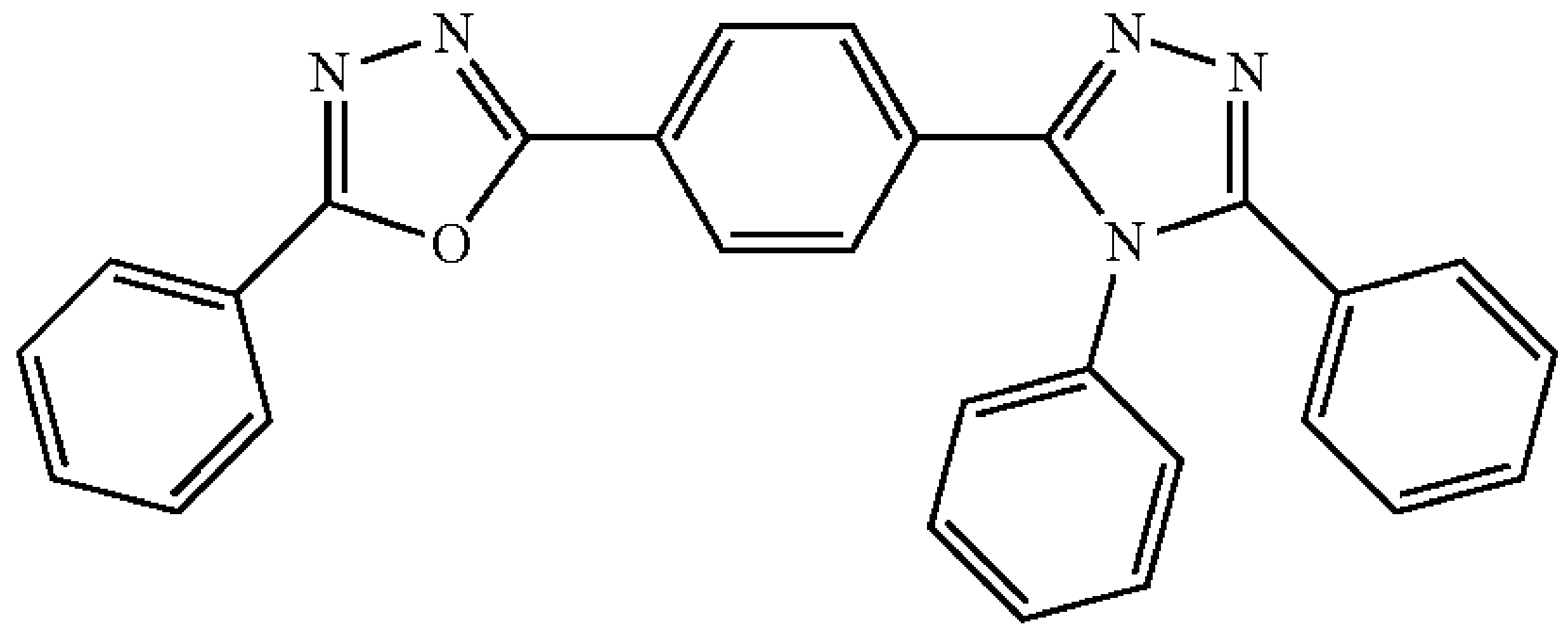
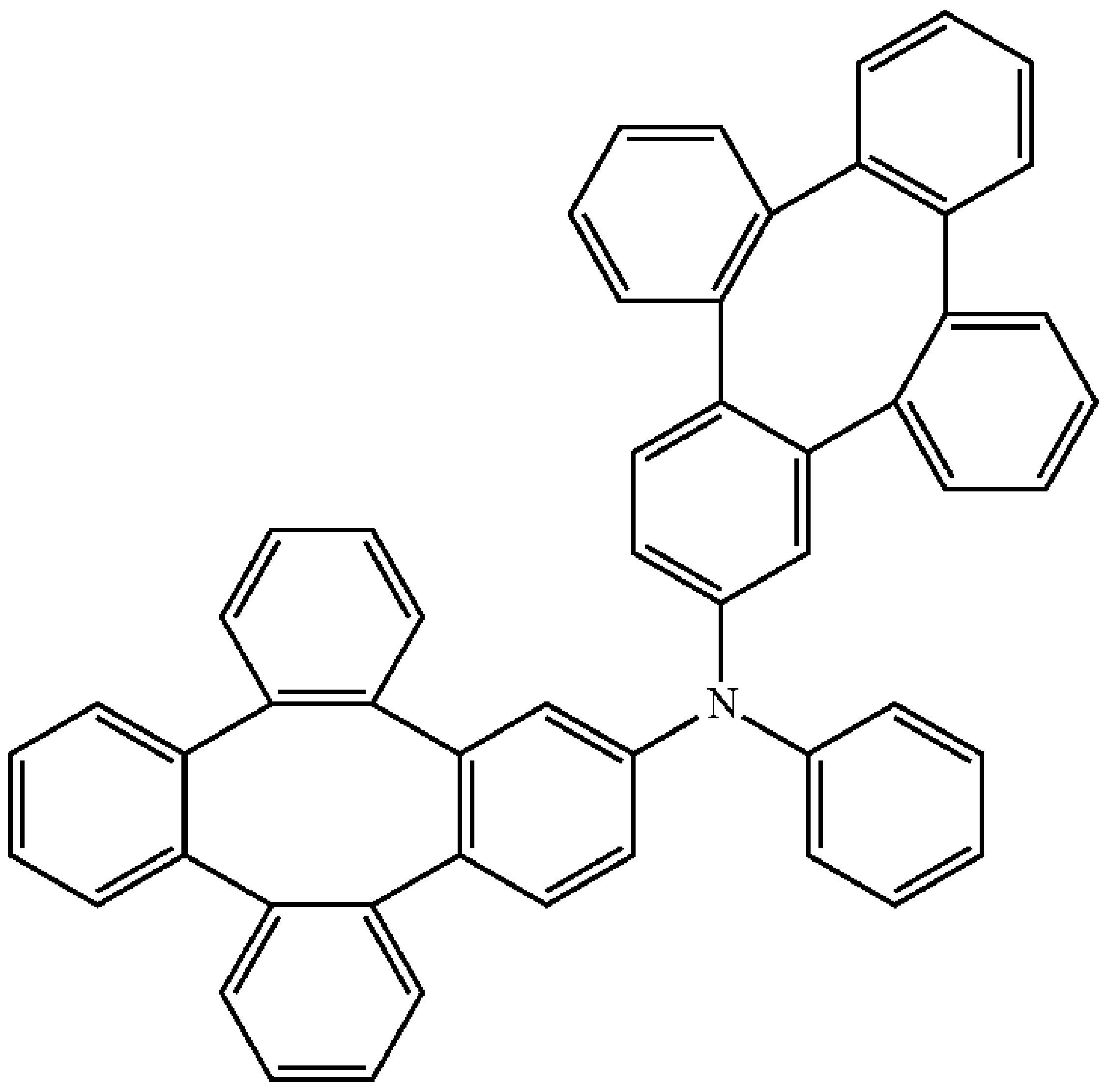
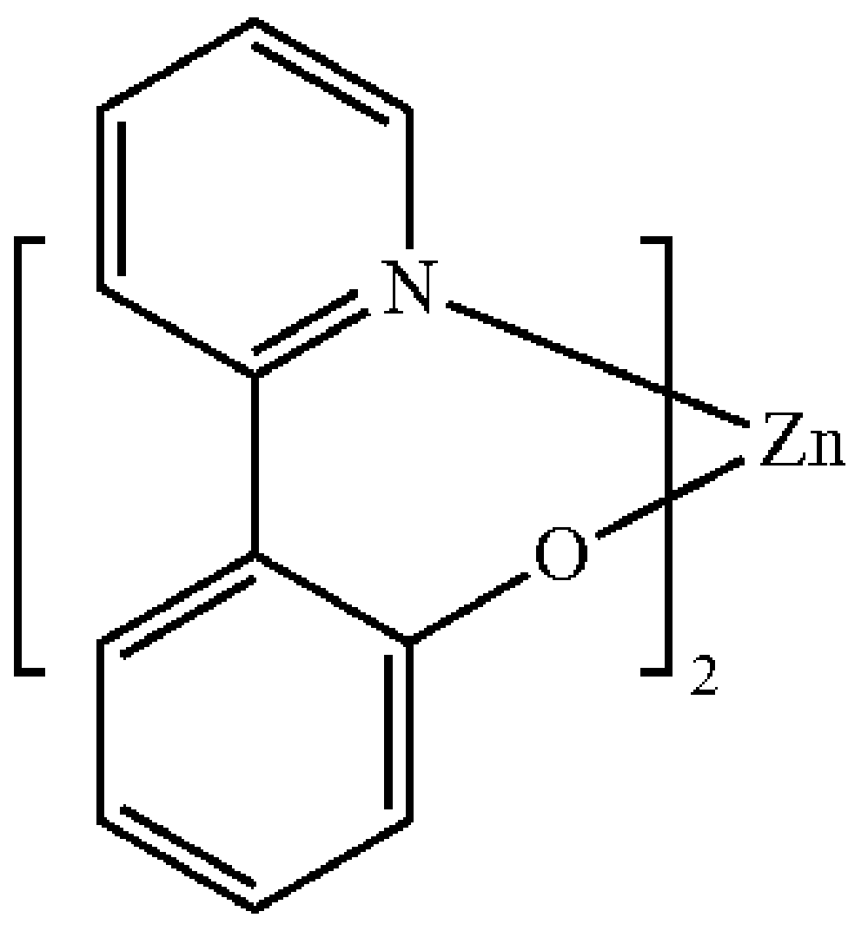
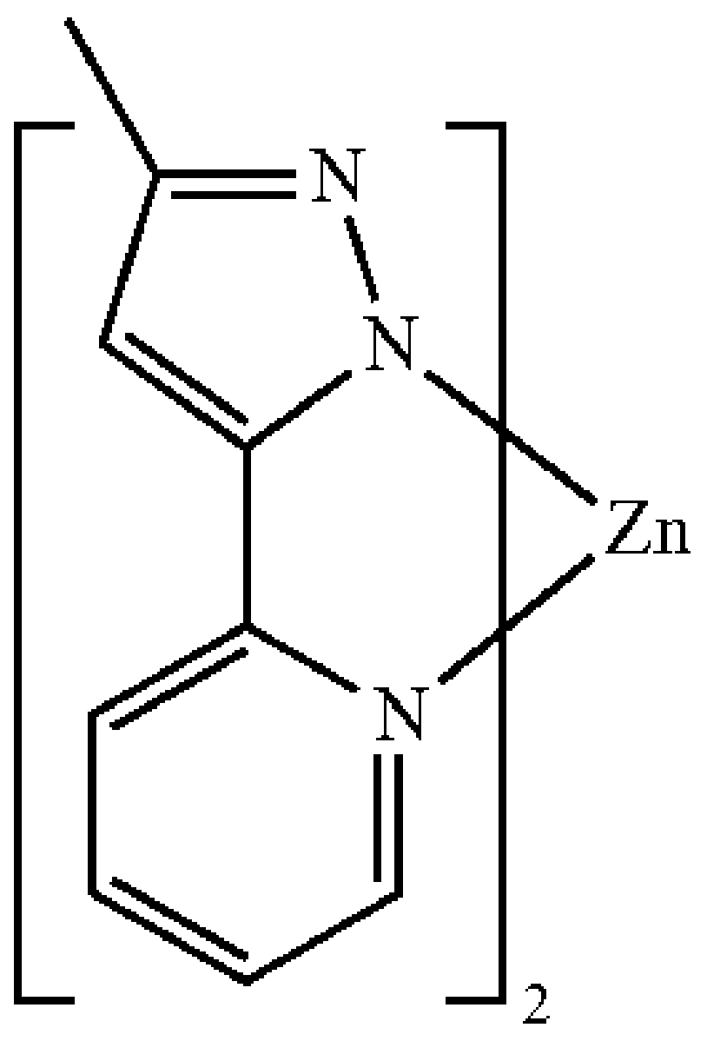
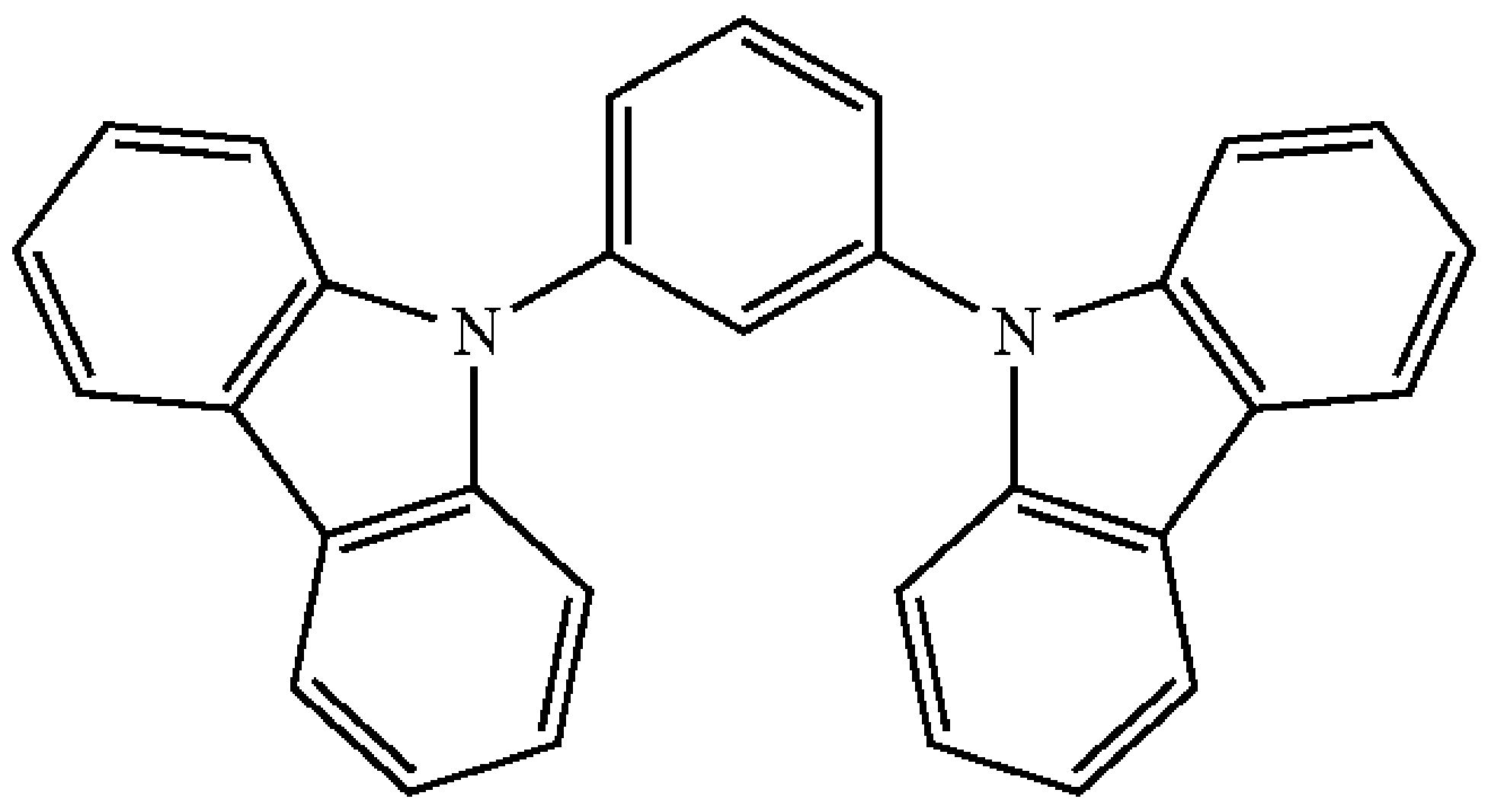
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		WO2004107822
Tetraphenylene complexes		US20050112407
Metal phenoxypyridine compounds		WO2005030900
Metal coordination complexes (e.g., Zn, Al with N^N ligands)		US20040137268, US20040137267
	Blue hosts	
Arylcarbazoles		Appl. Phys. Lett, 82, 2422 (2003)

TABLE 4-continued

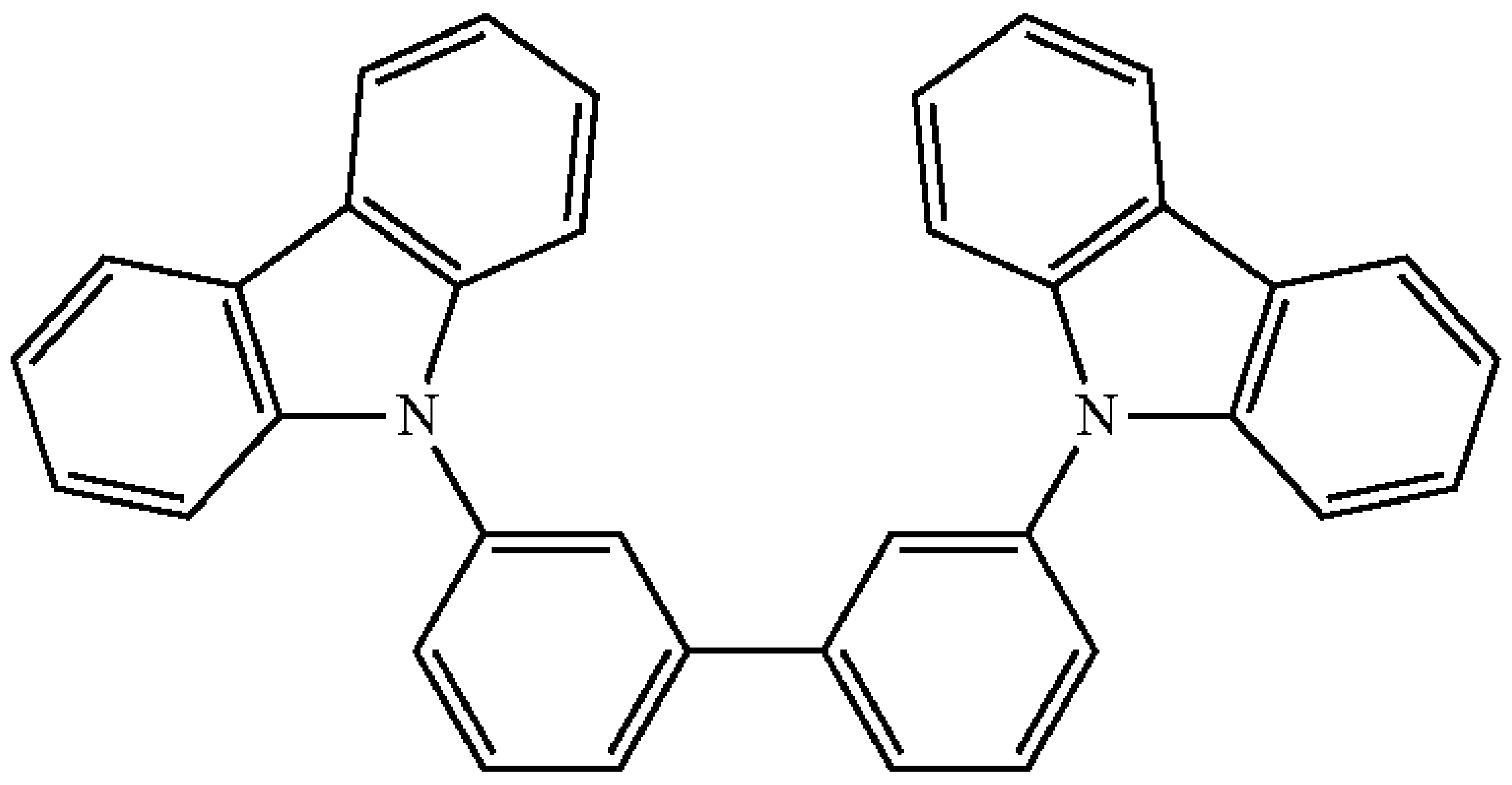
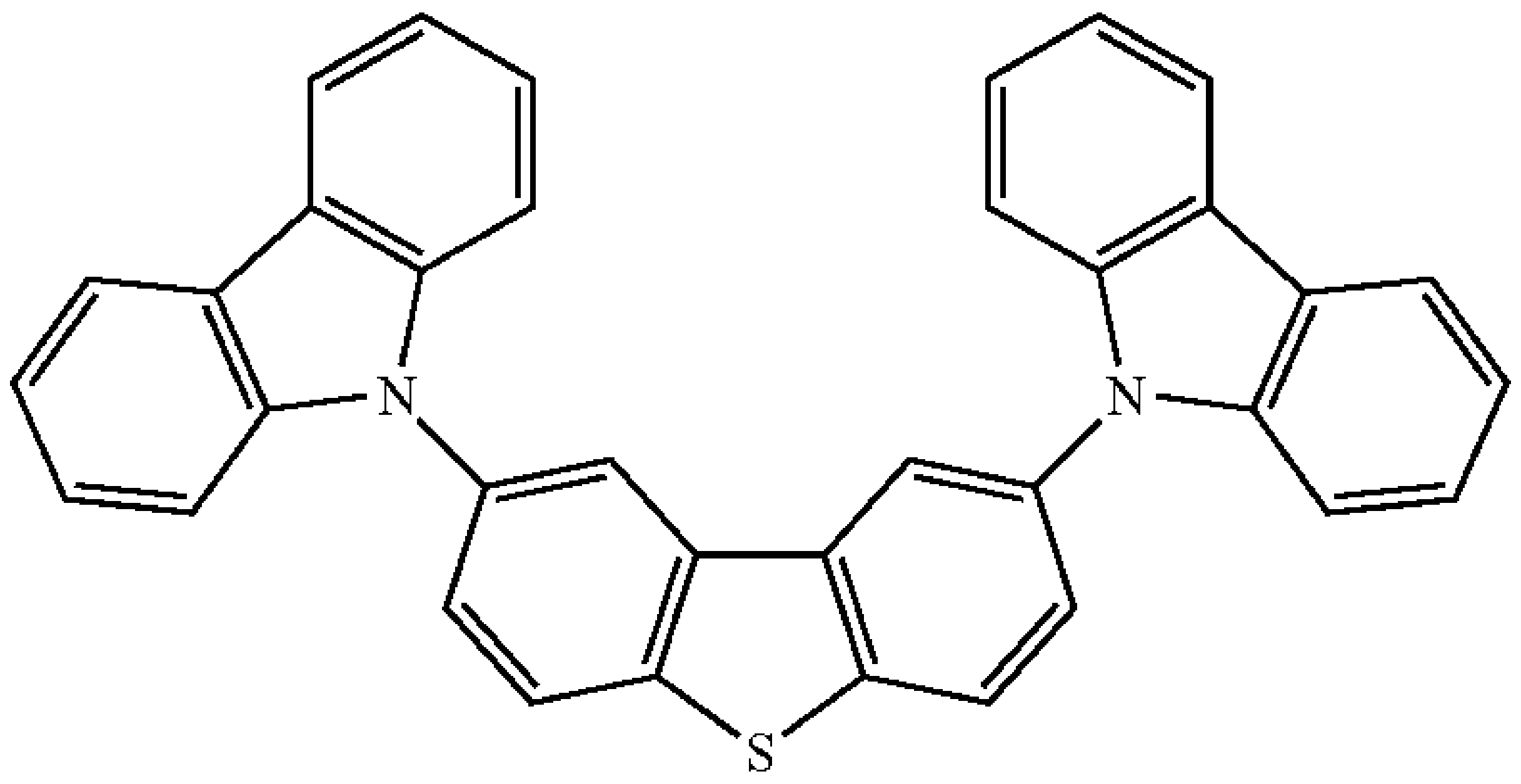
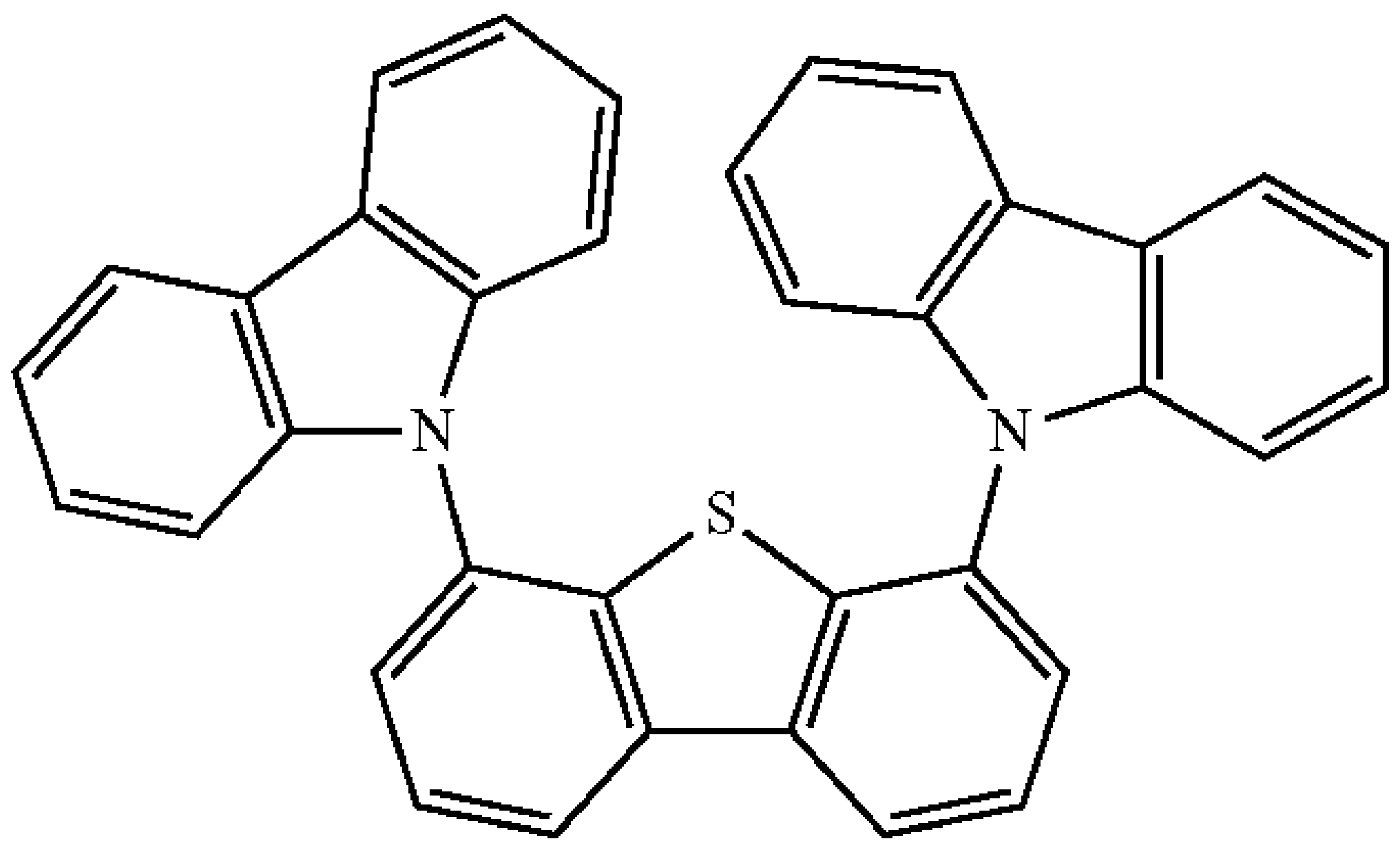
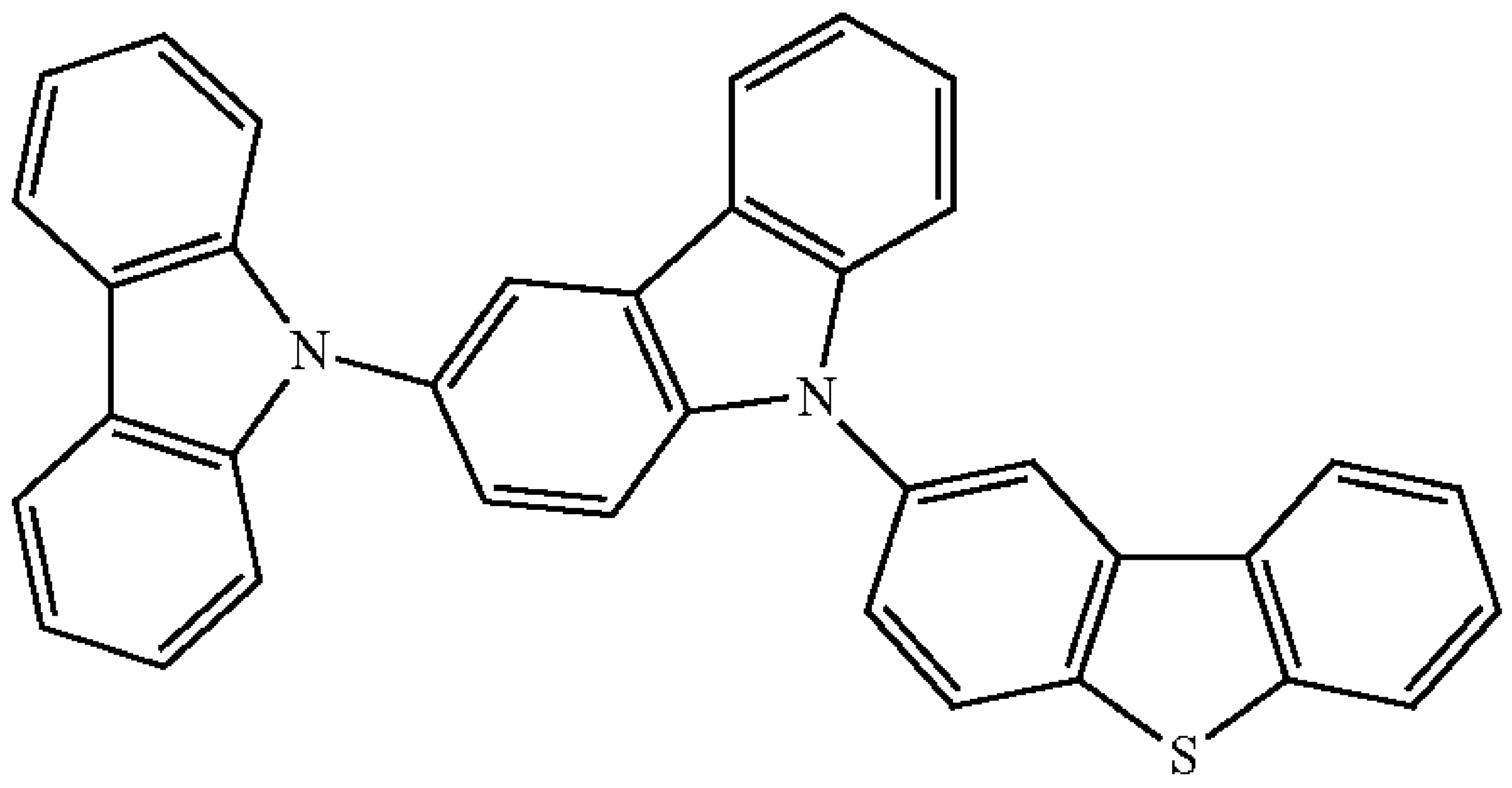
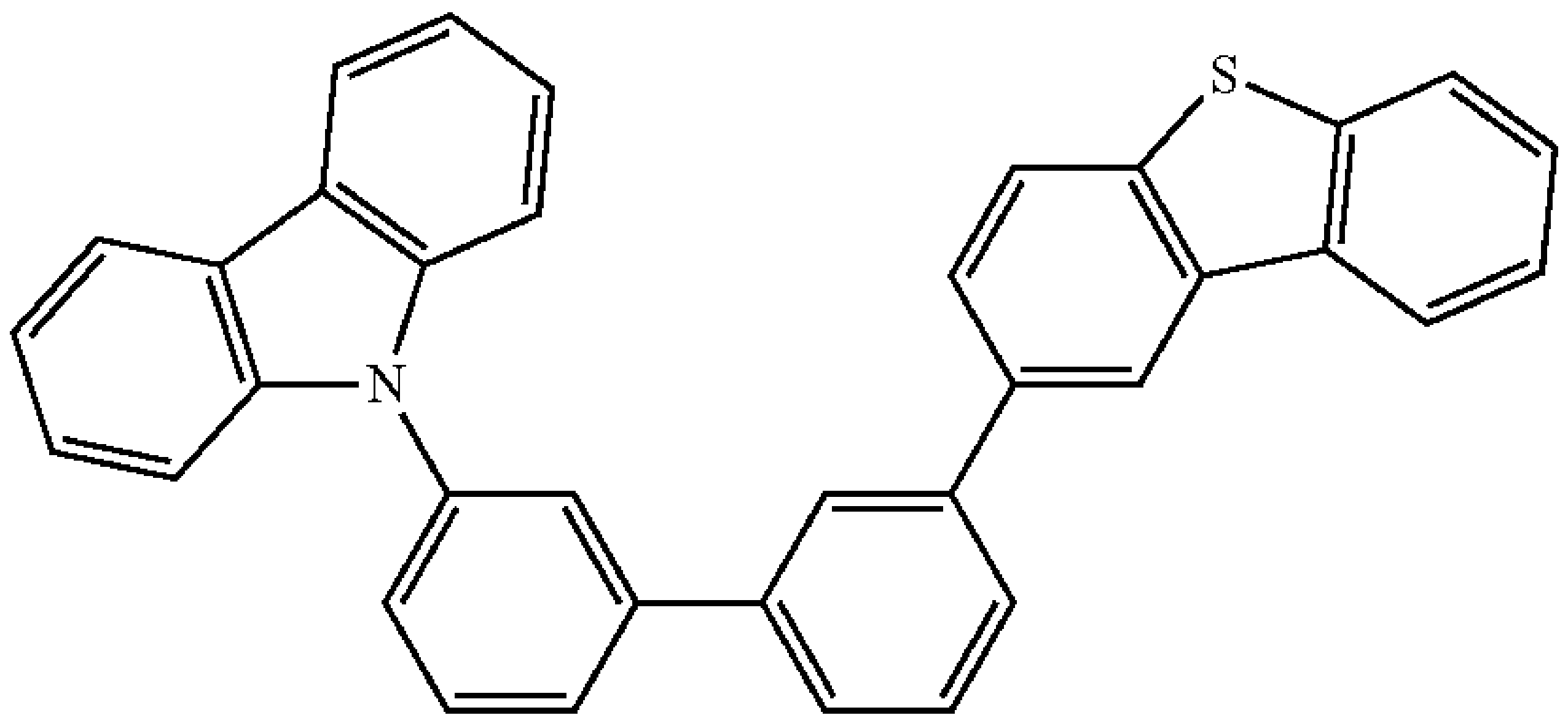
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		US20070190359
Dibenzothiophene/ Dibenzofuran-carbazole compounds		WO2006114966, US20090167162
		US20090167162
		WO2009086028
		US20090030202, US20090017330

TABLE 4-continued

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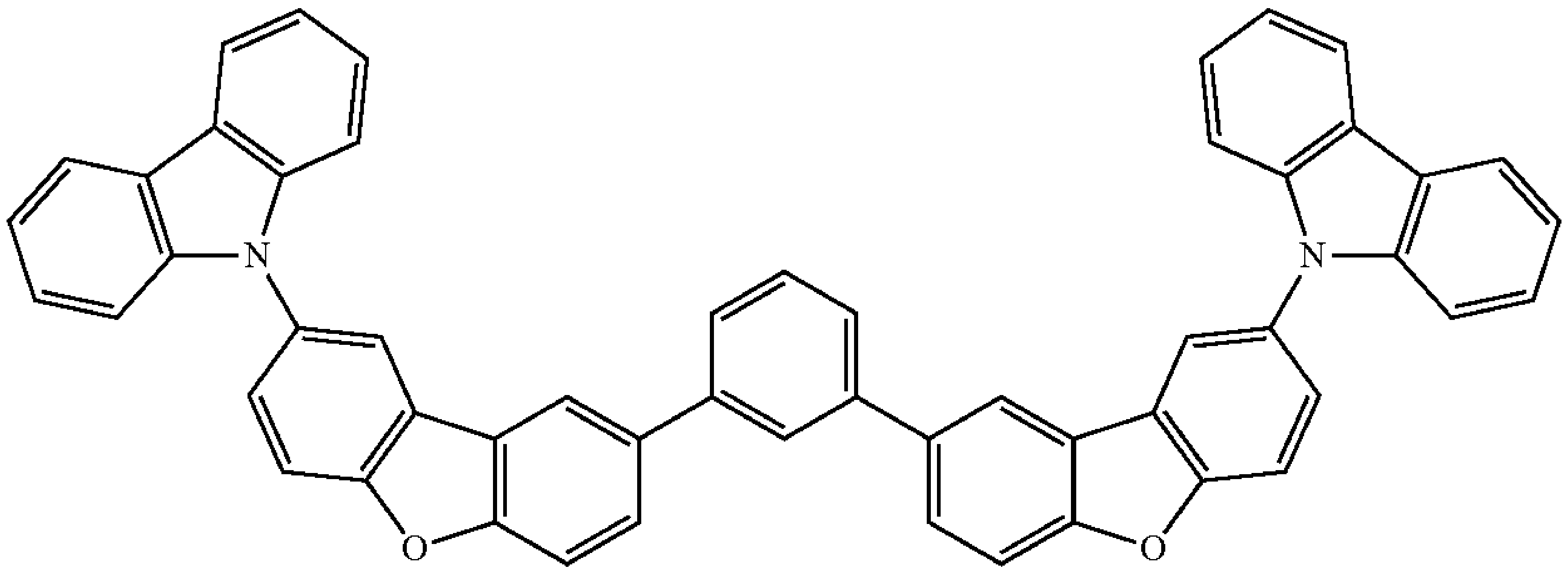
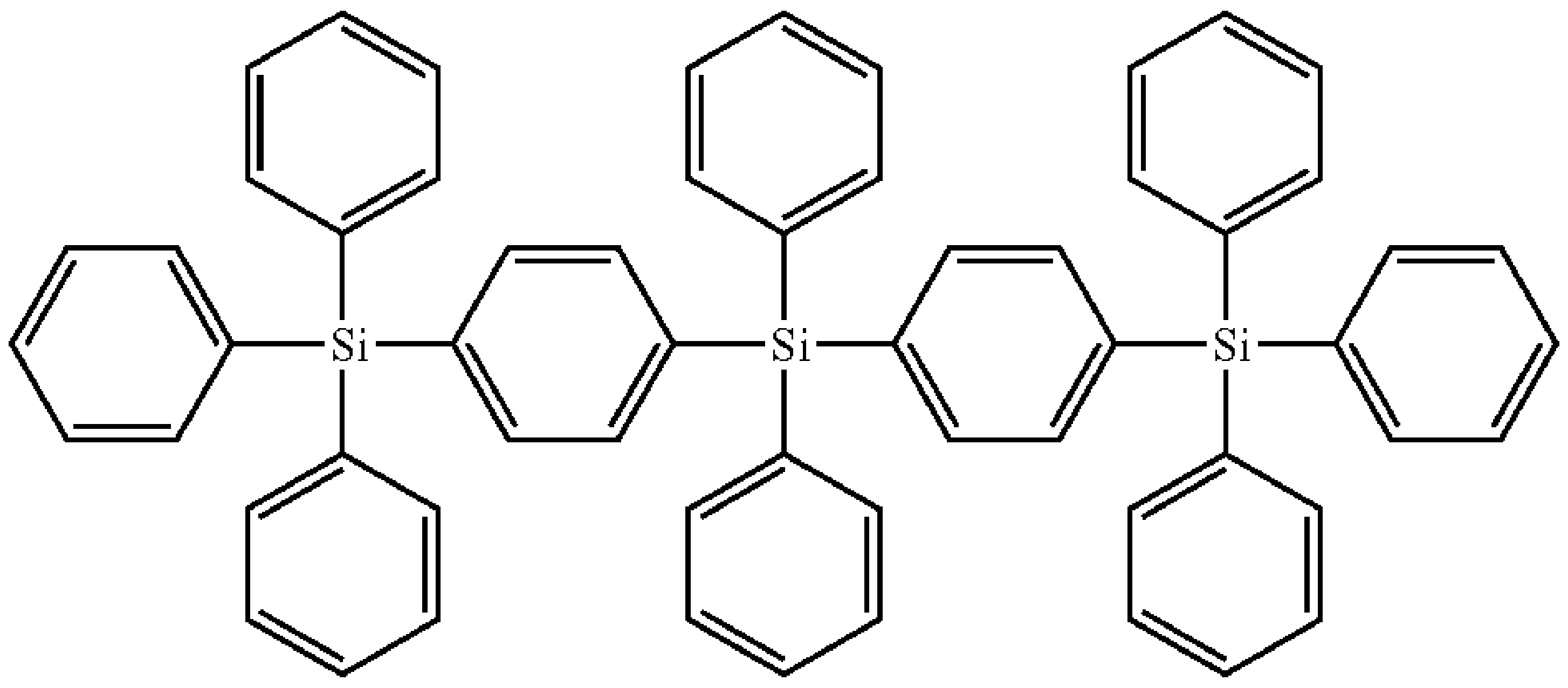
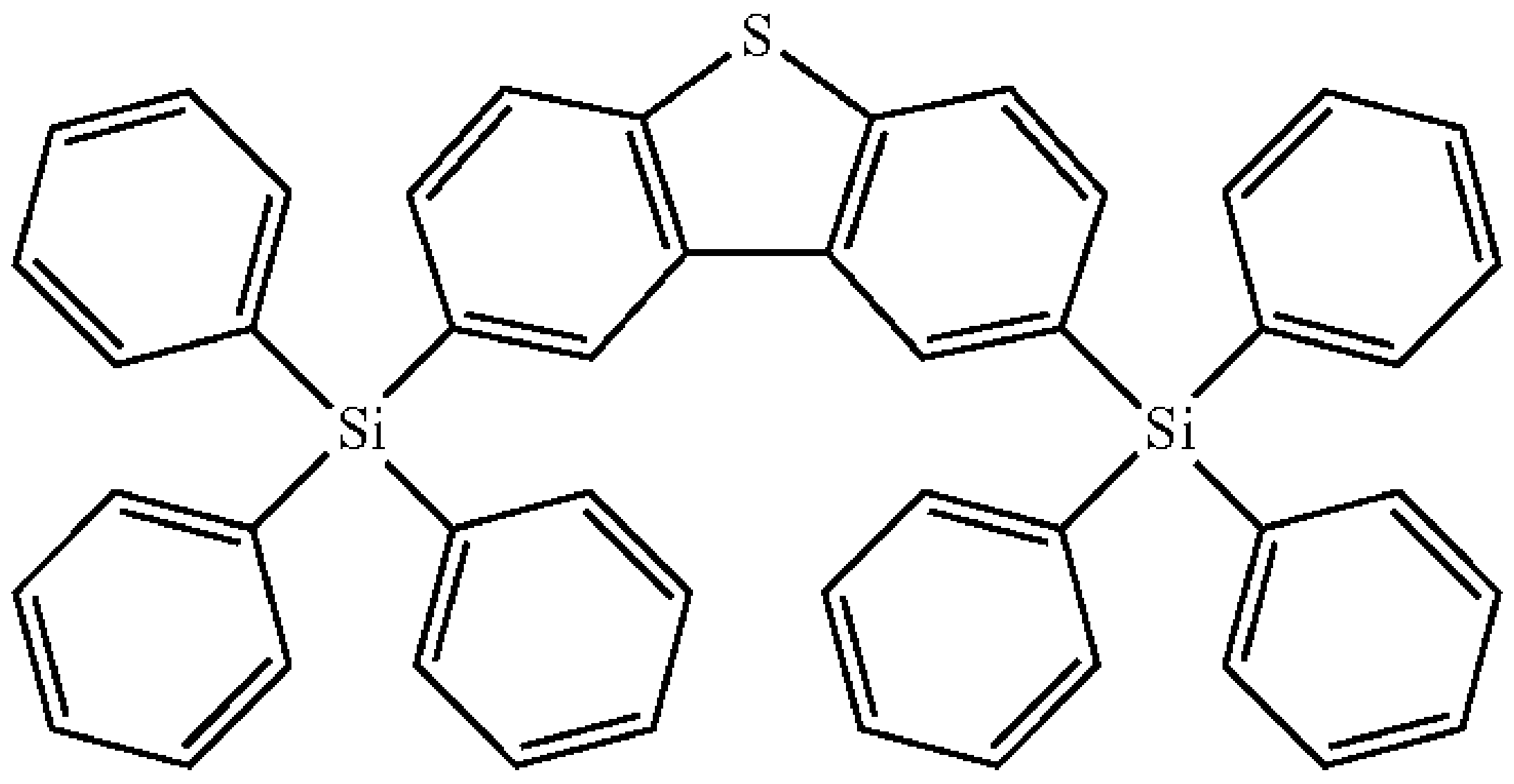
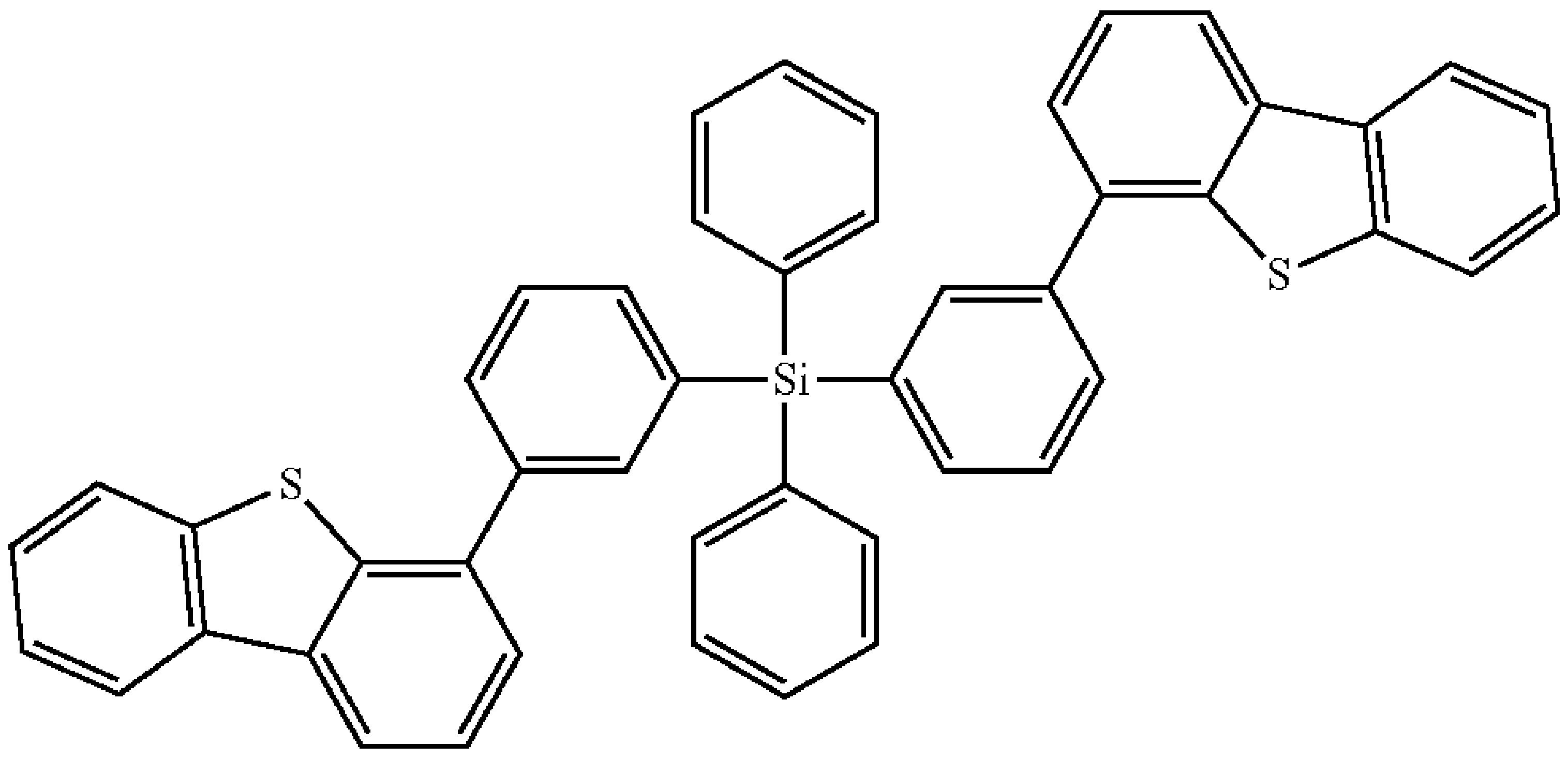
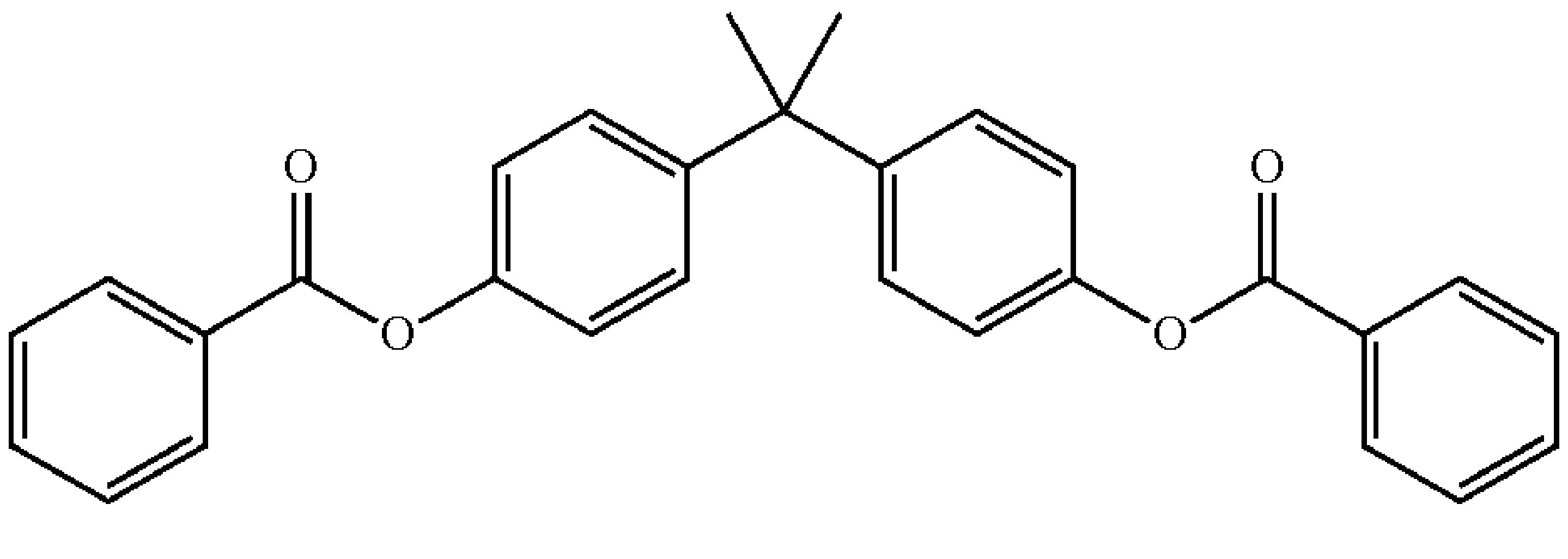
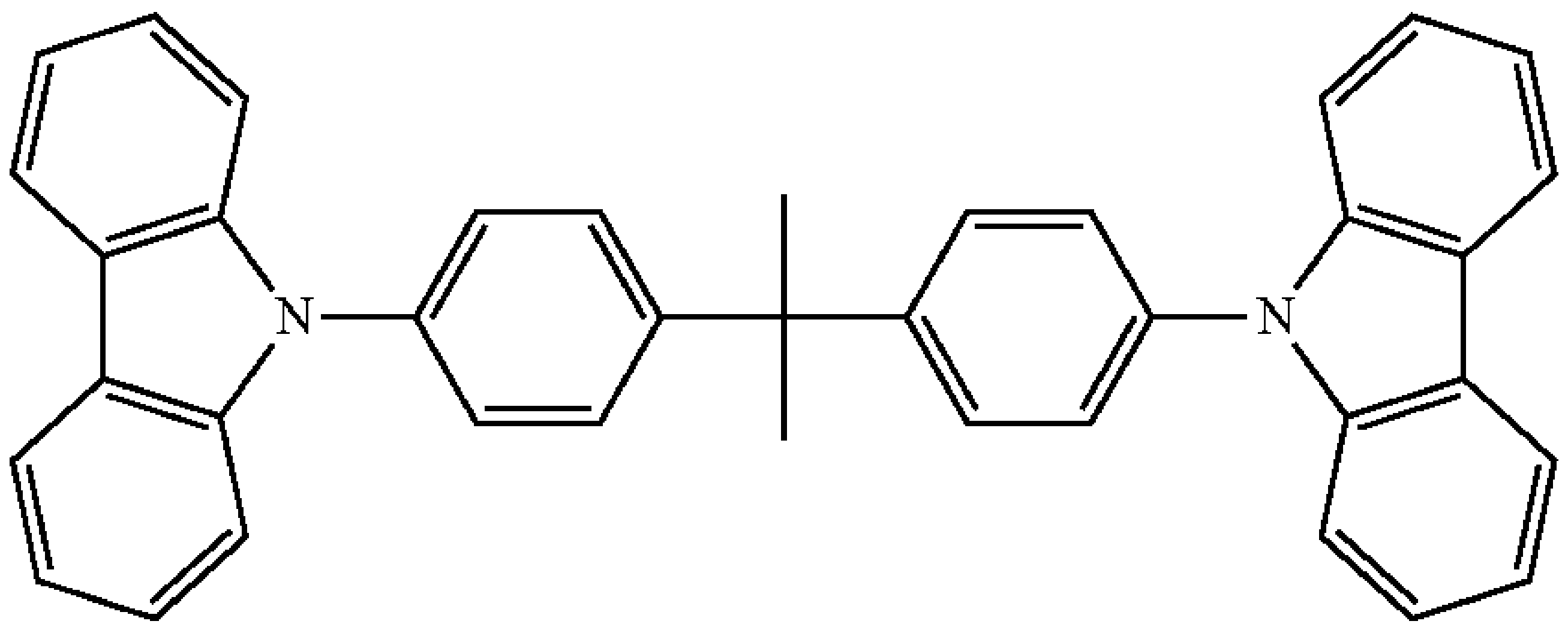
		US20100084966
Silicon aryl compounds		US20050238919
		WO2009003898
Silicon/ Germanium aryl compounds		EP2034538A
Aryl benzoyl ester		WO2006100298
Carbazole linked by non-conjugated groups		US20040115476

TABLE 4-continued

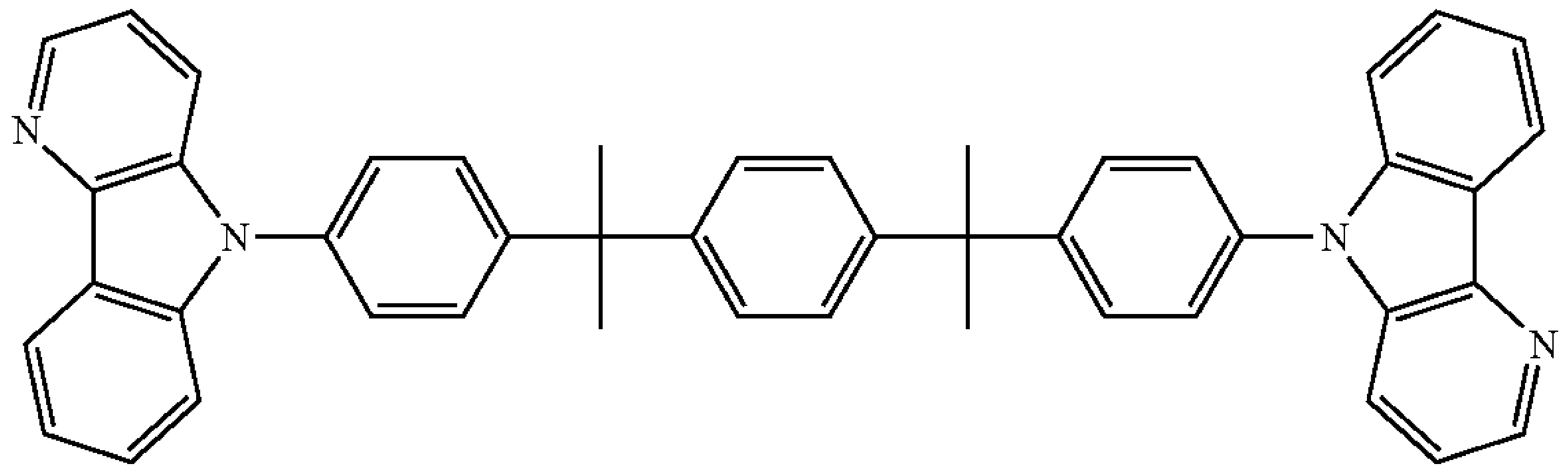
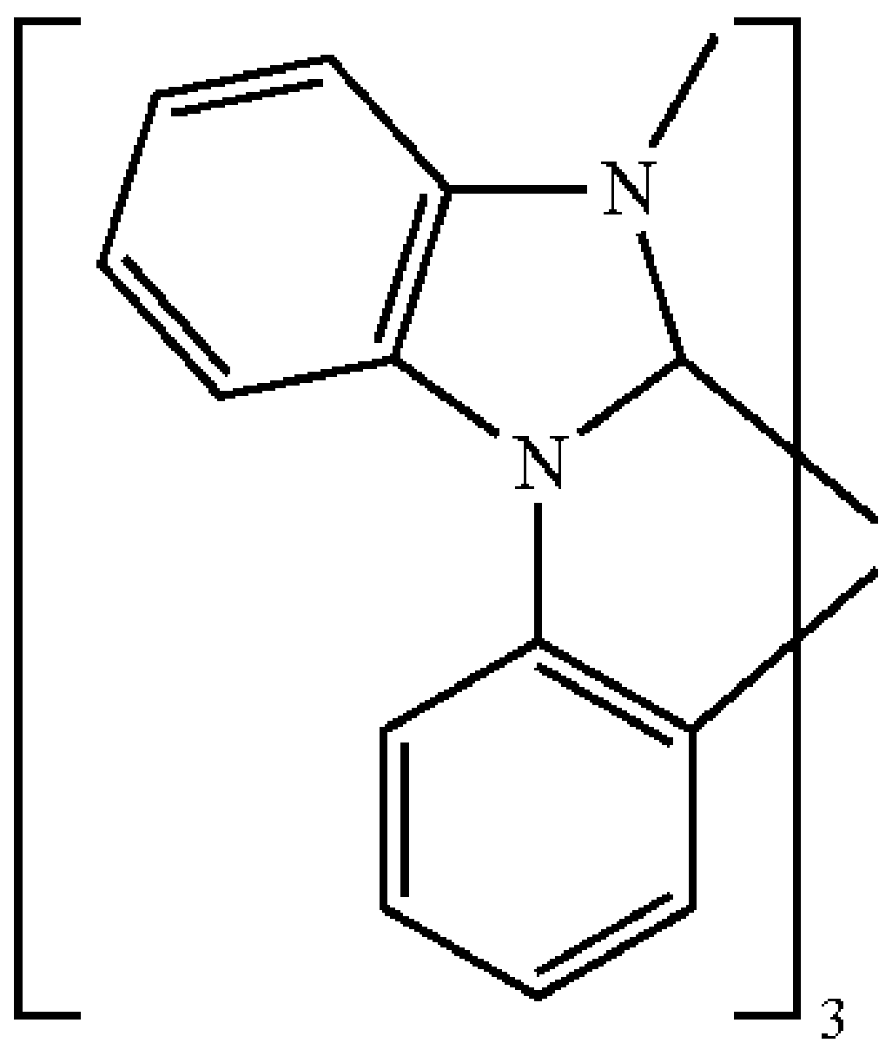
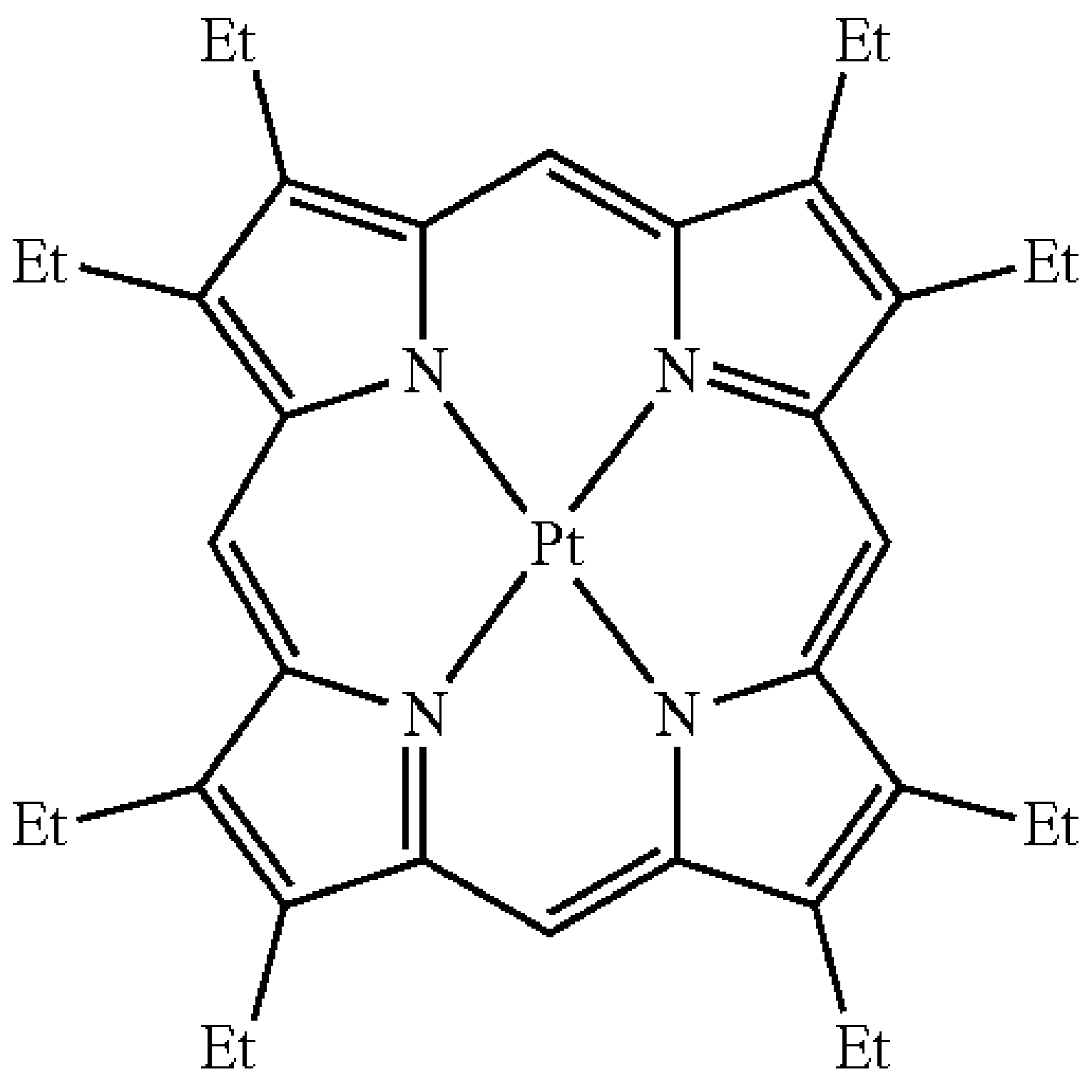
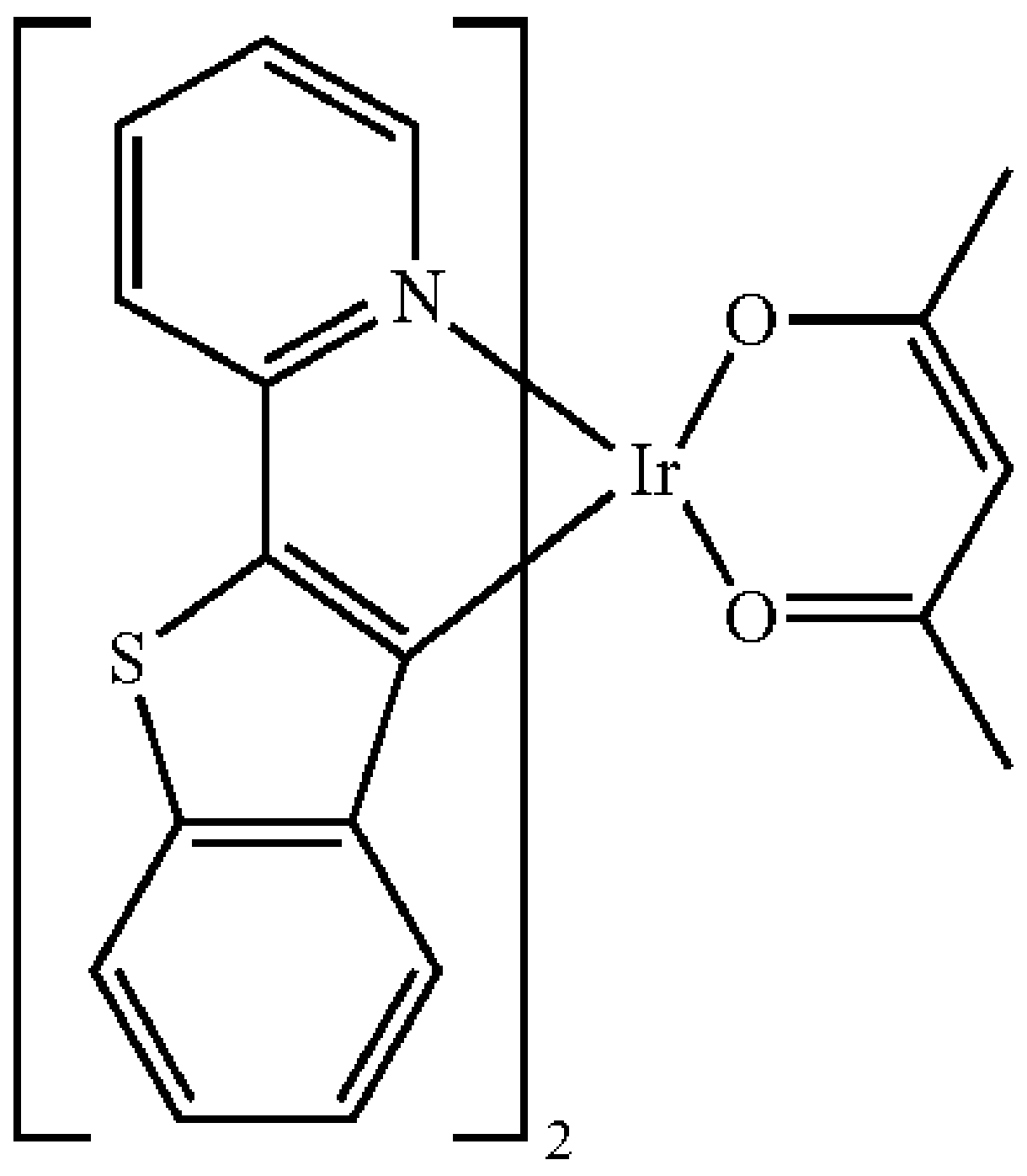
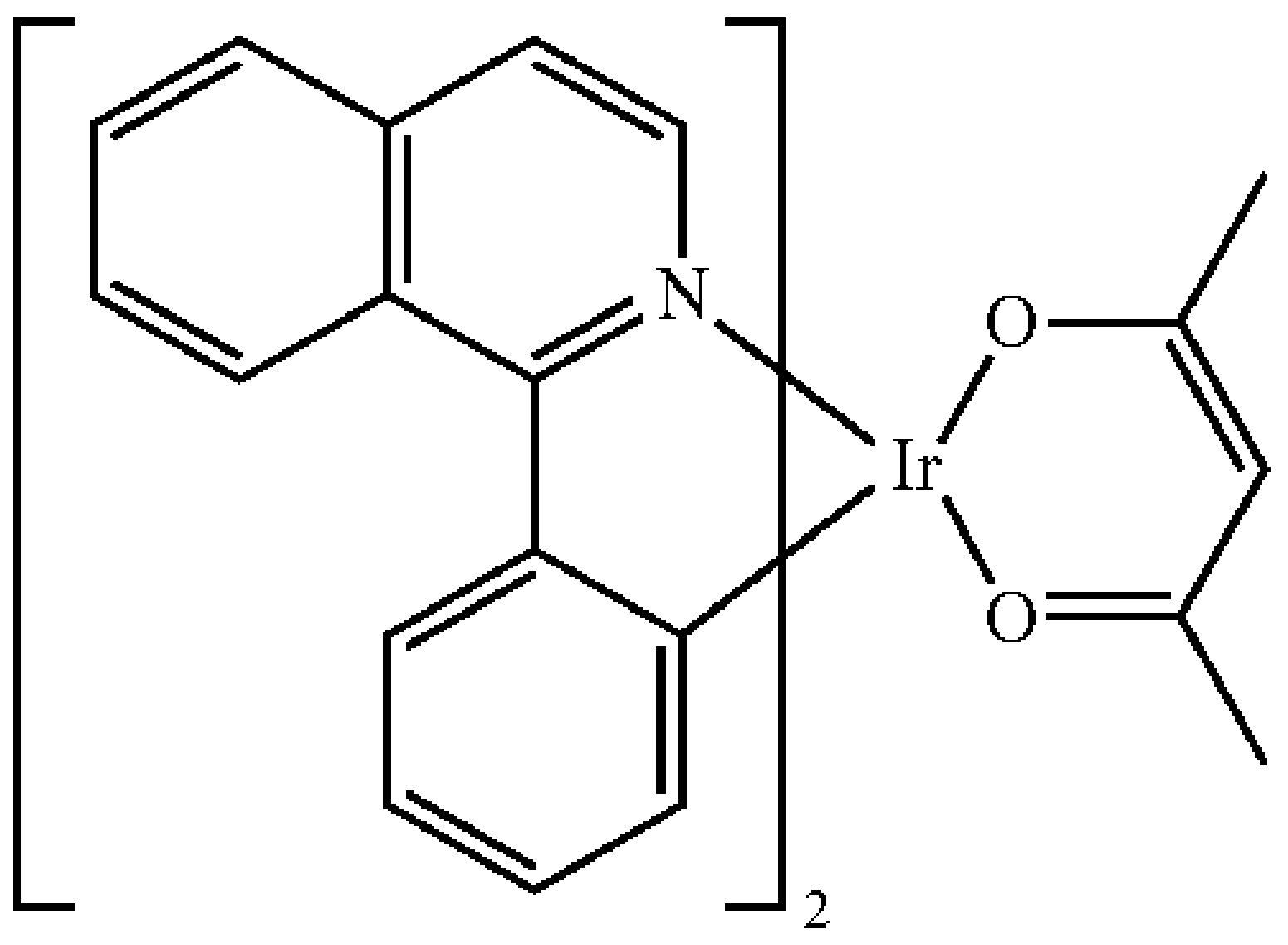
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Aza-carbazoles		US20060121308
High triplet metal organometallic complex		U.S. Pat. No. 7,154,114
	Phosphorescent dopants Red dopants	
Heavy metal porphyrins (e.g., PtOEP)		Nature 395, 151 (1998)
Iridium(III) organometallic complexes		Appl. Phys. Lett. 78, 1622 (2001)
		US2006835469

TABLE 4-continued

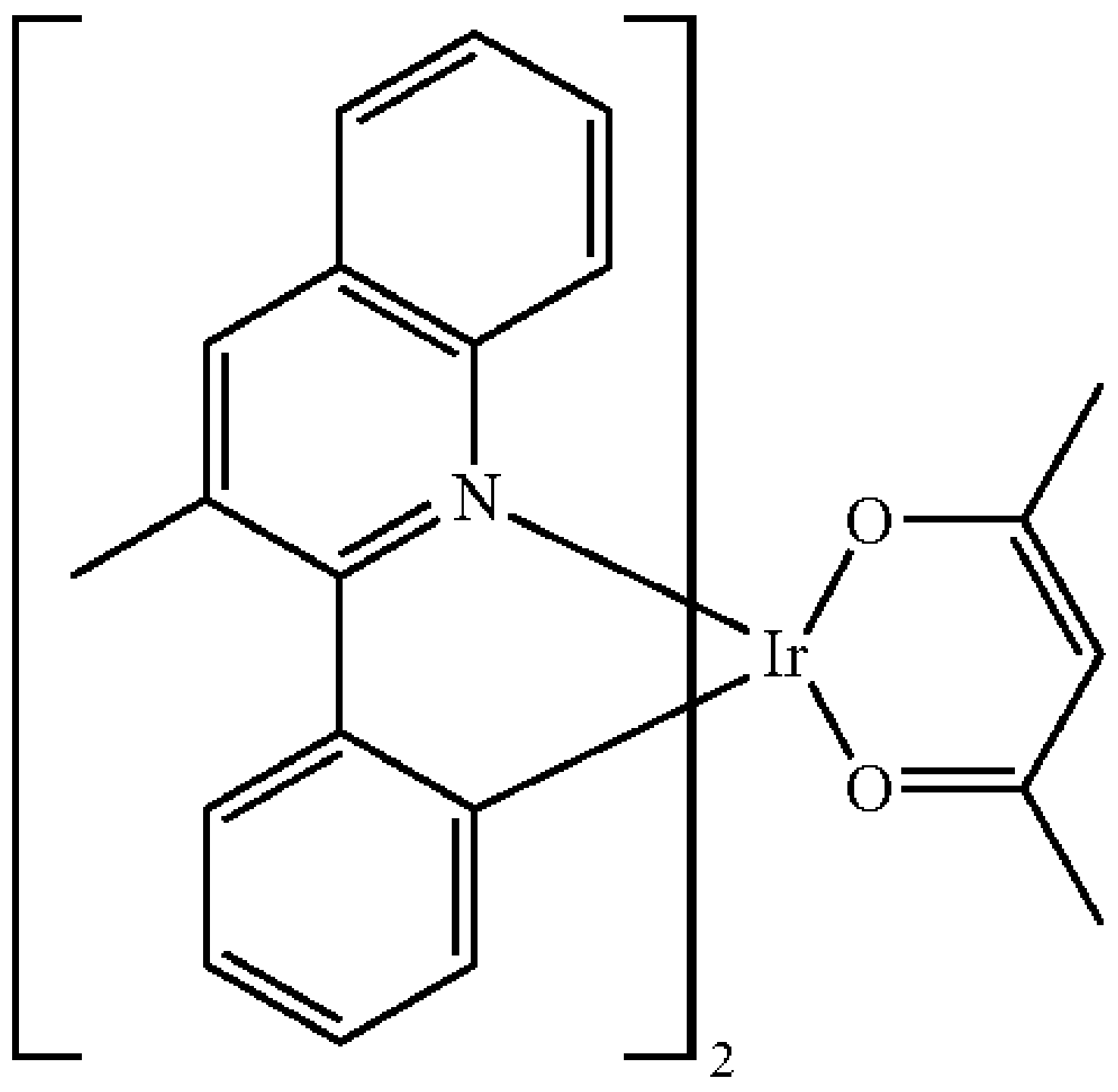
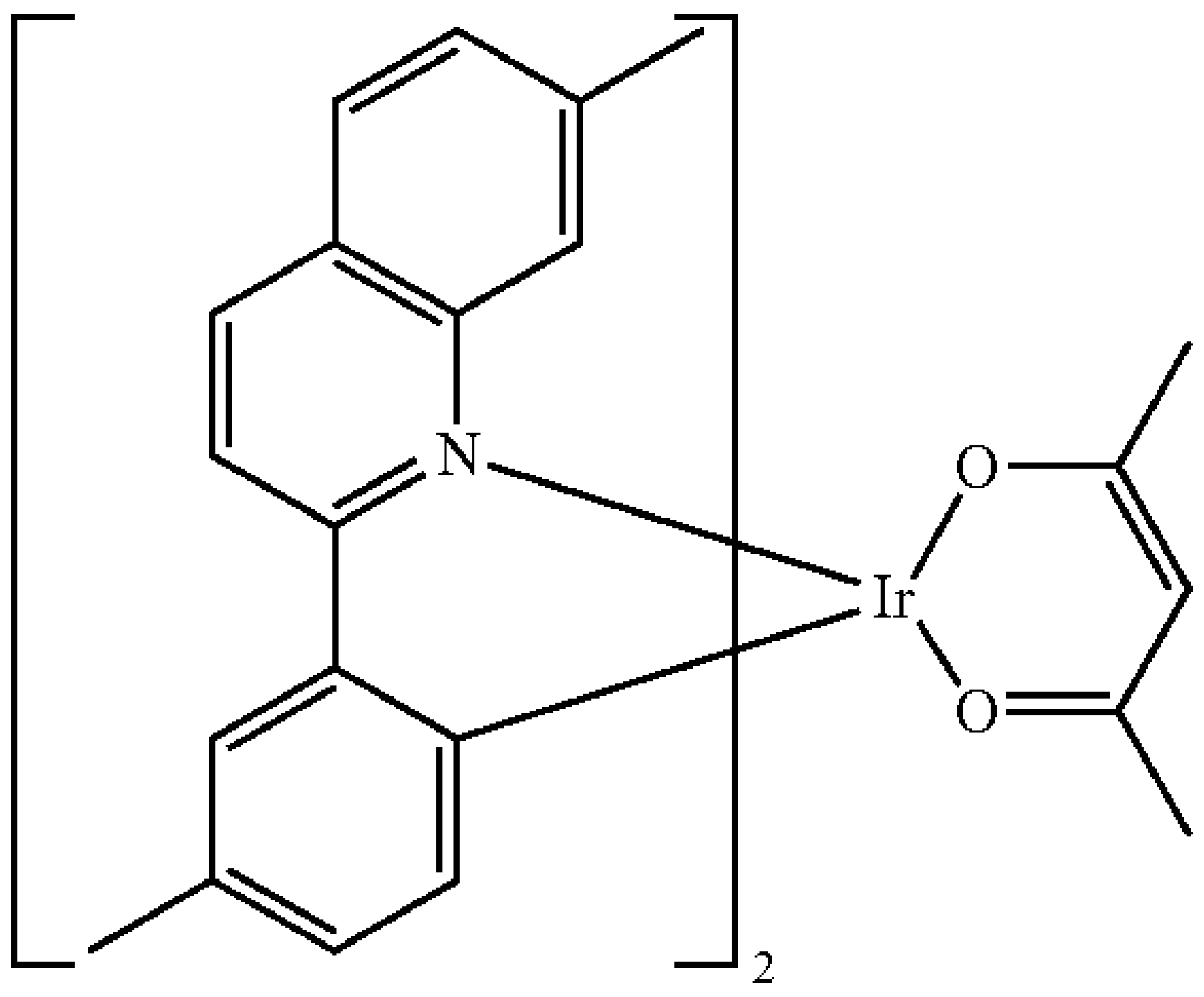
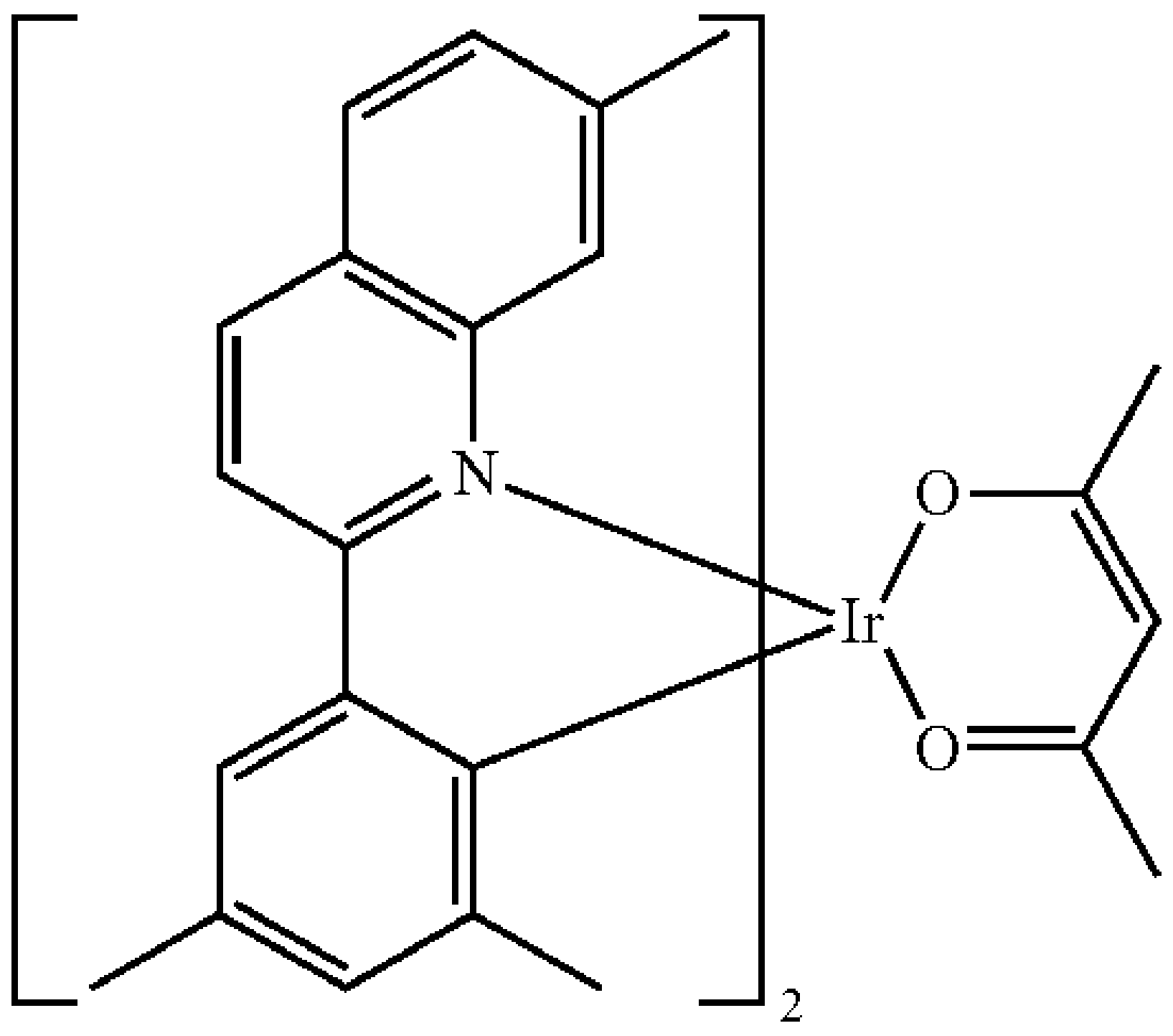
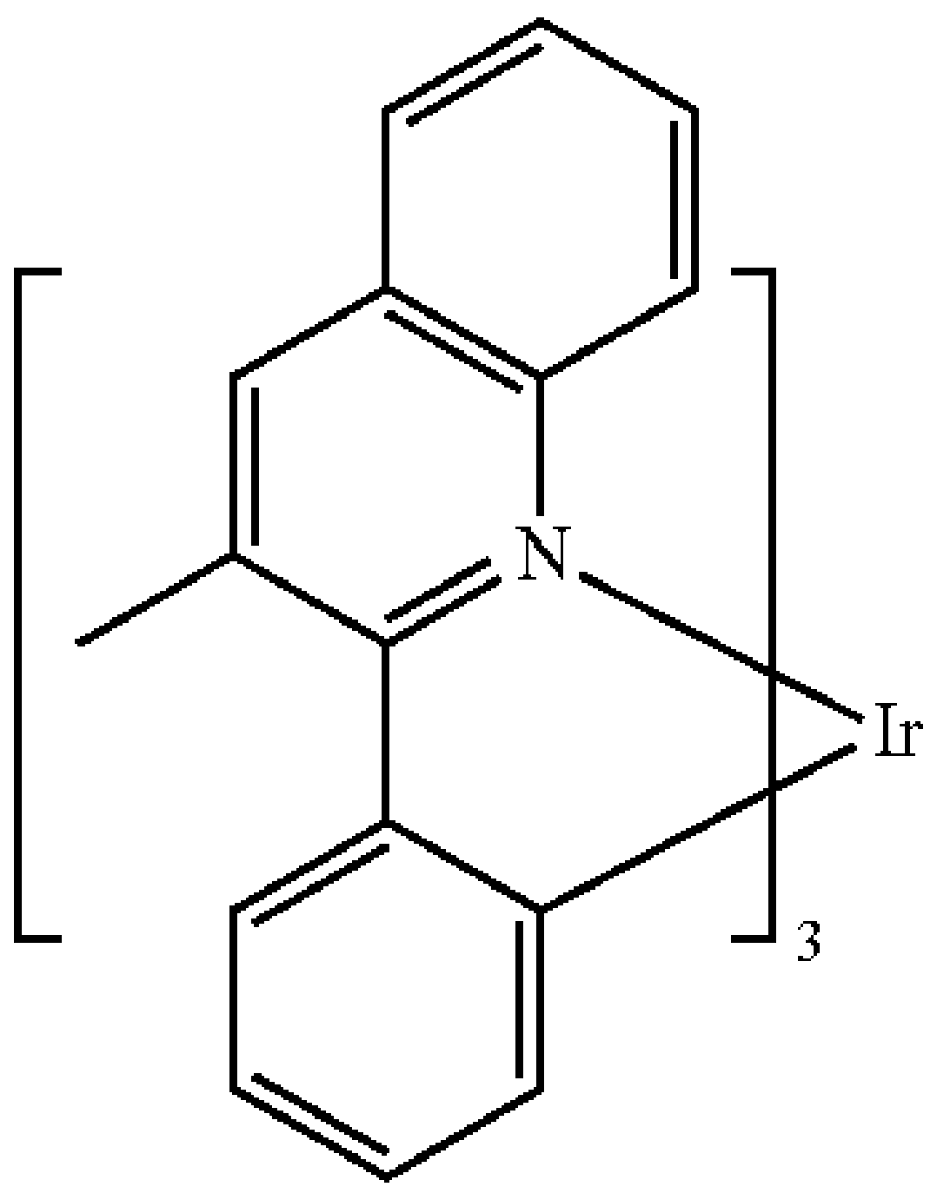
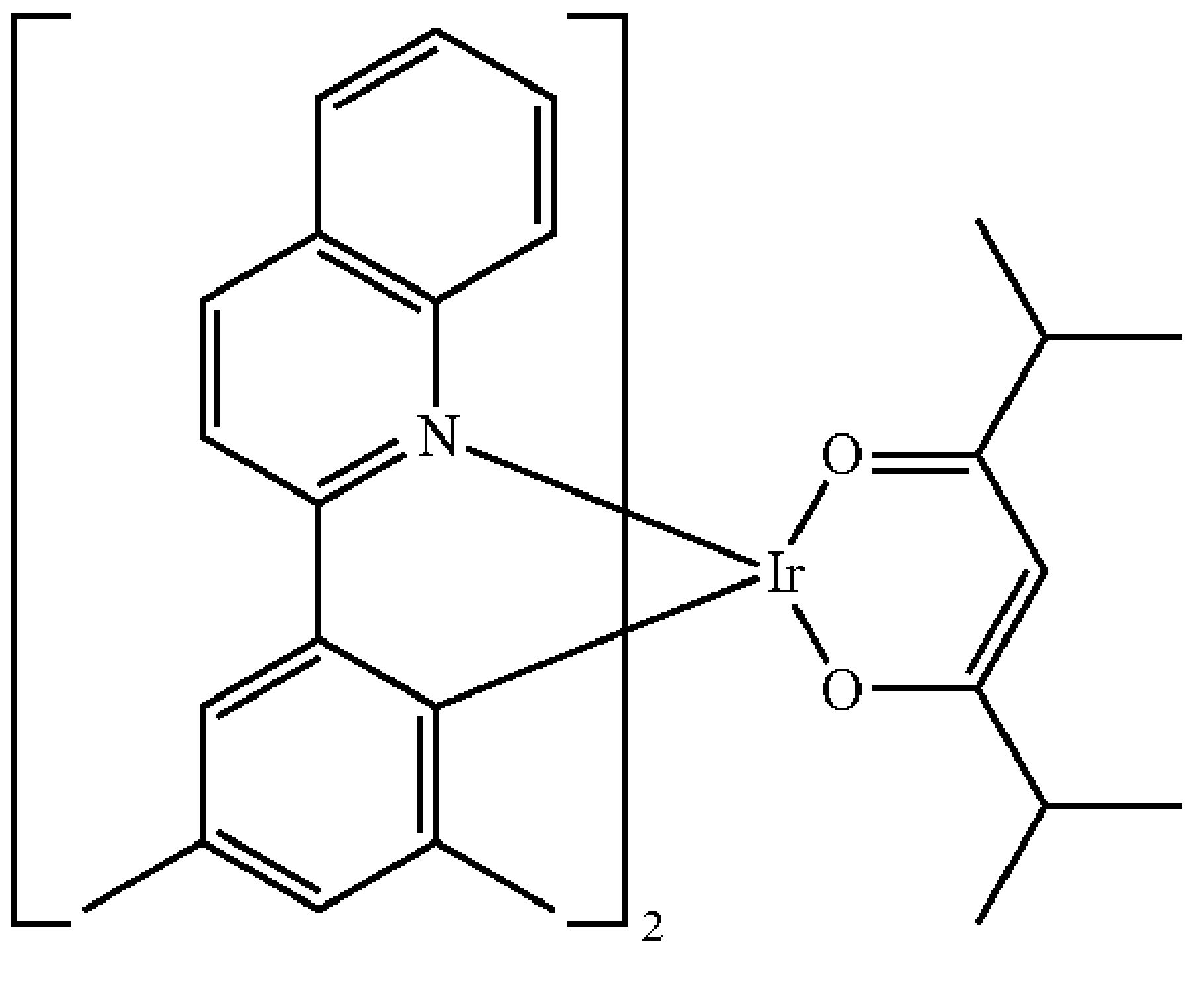
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		US2006835469
		US20060202194
		US20060202194
		US20070087321
		US20080261076 US20100090591

TABLE 4-continued

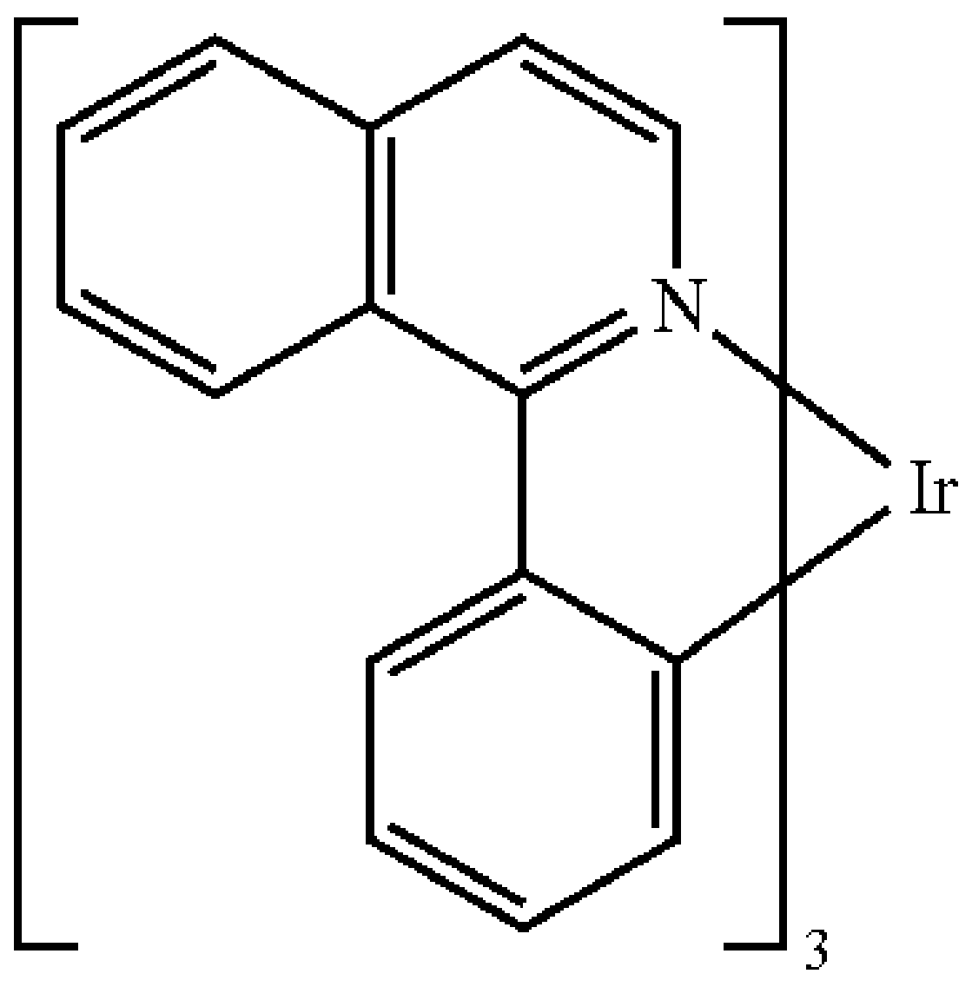
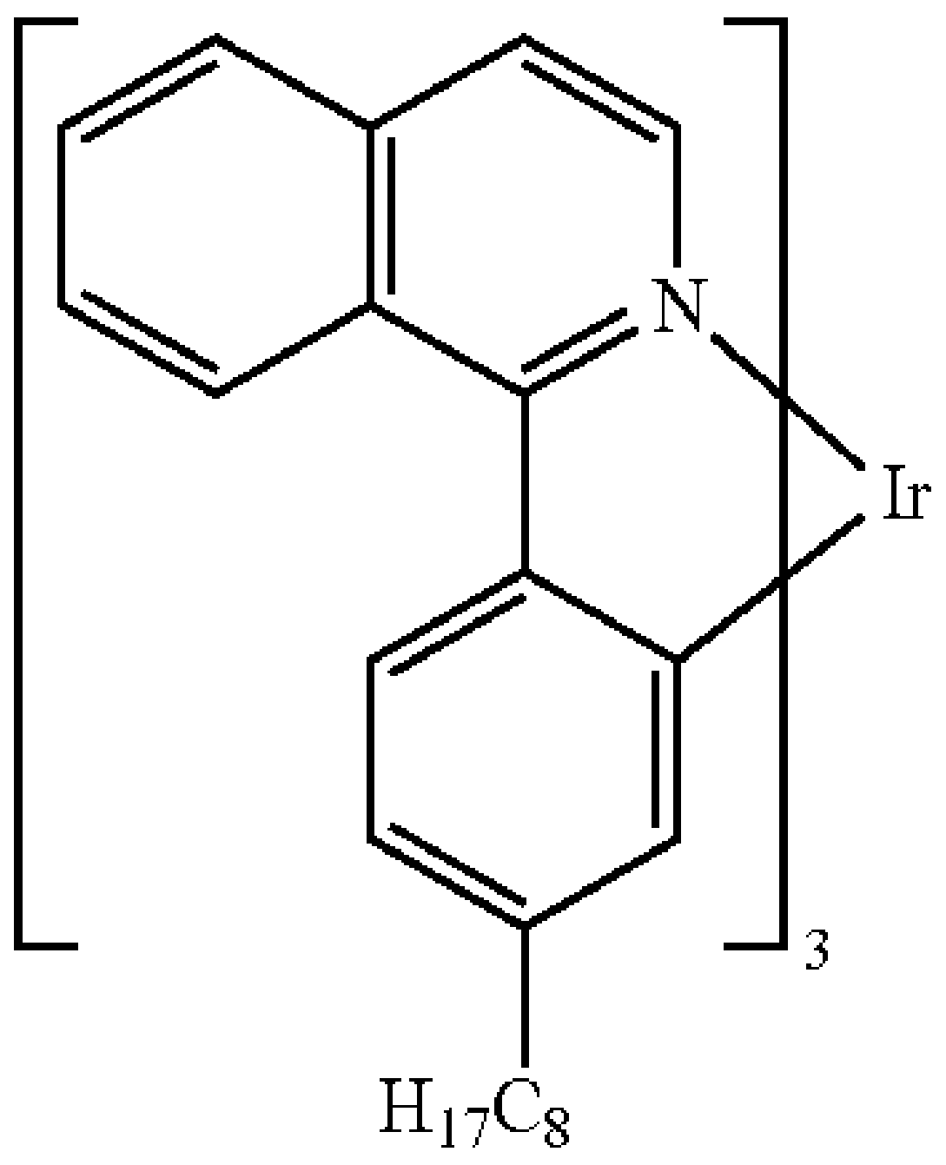
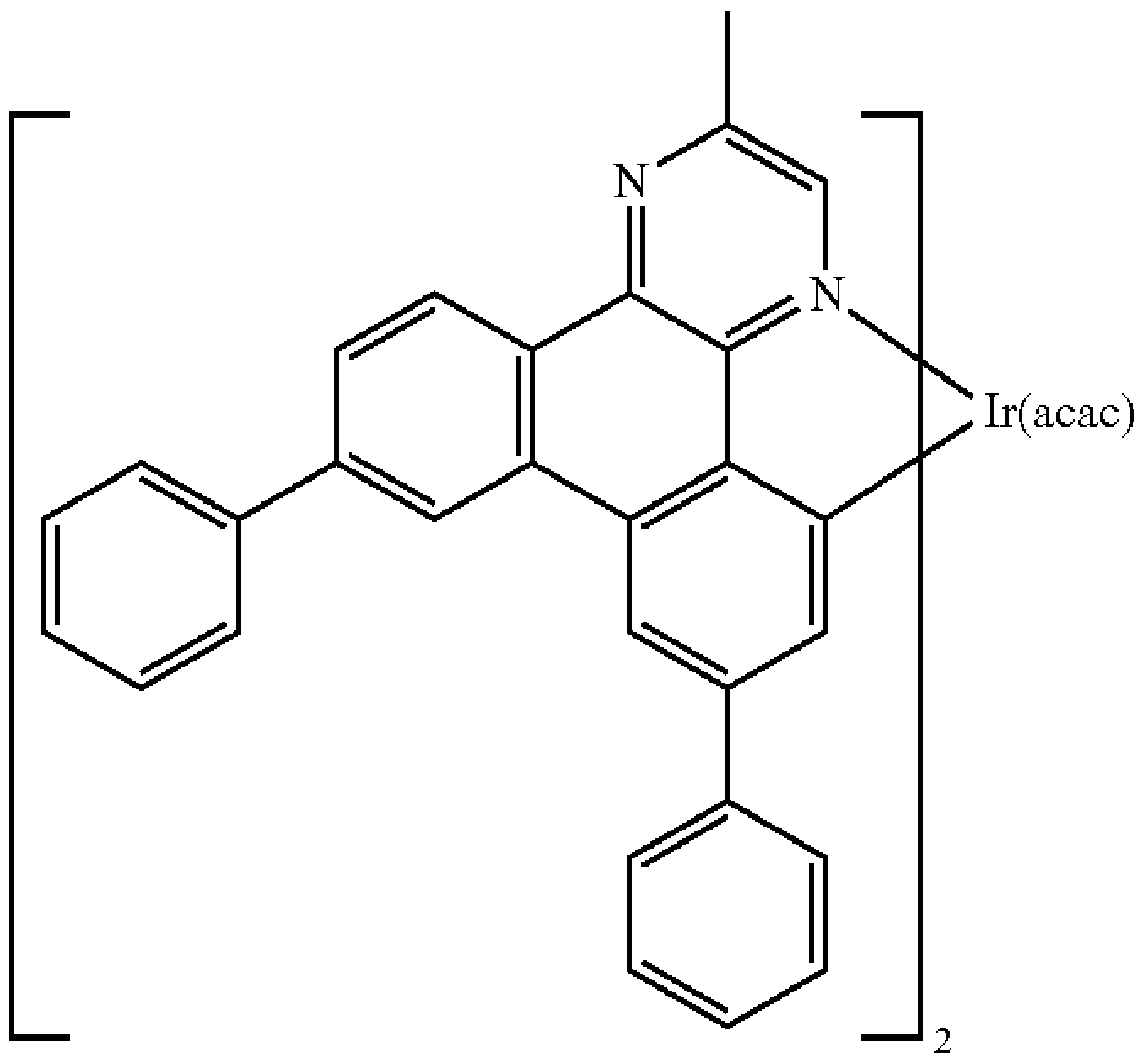
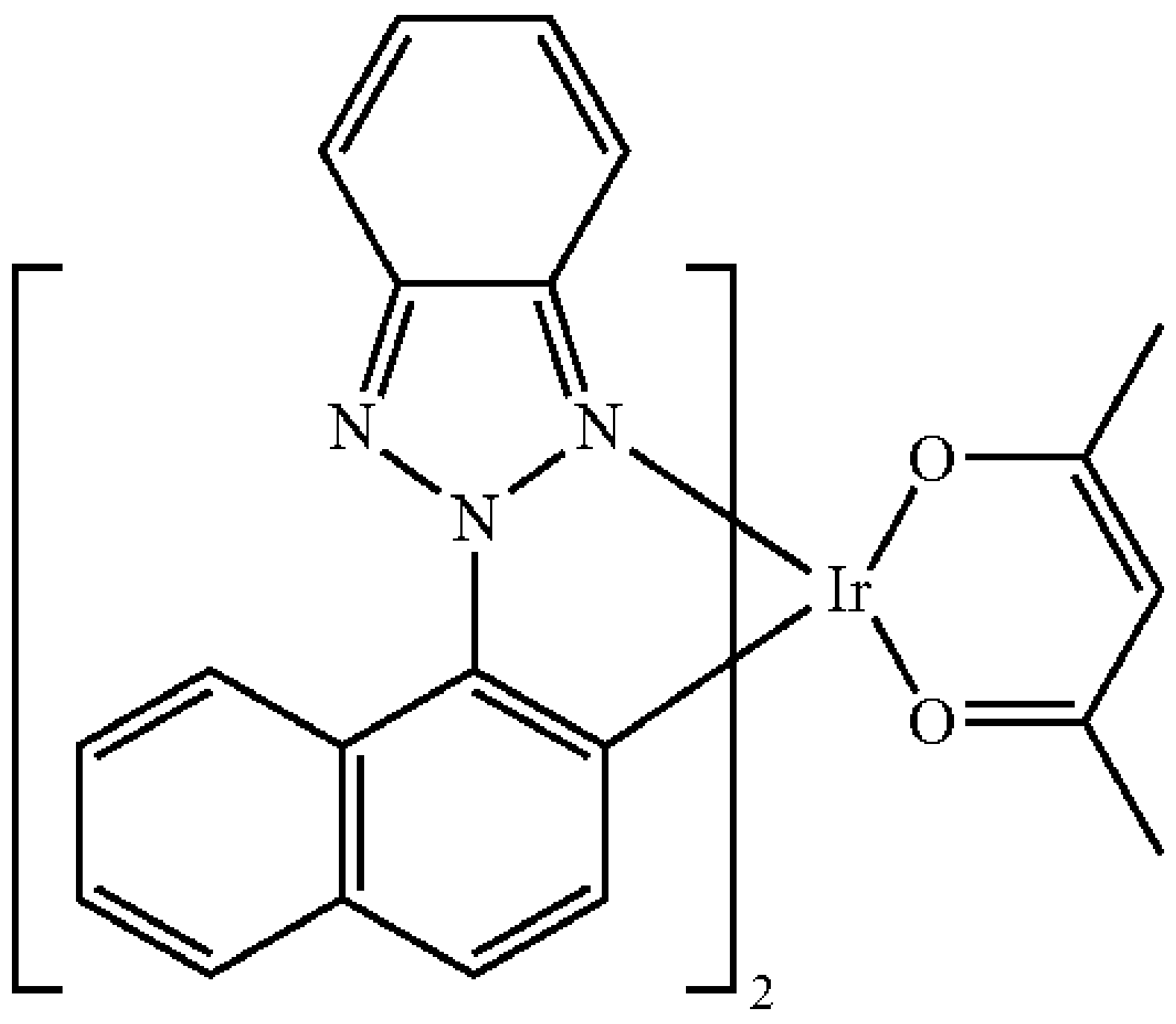
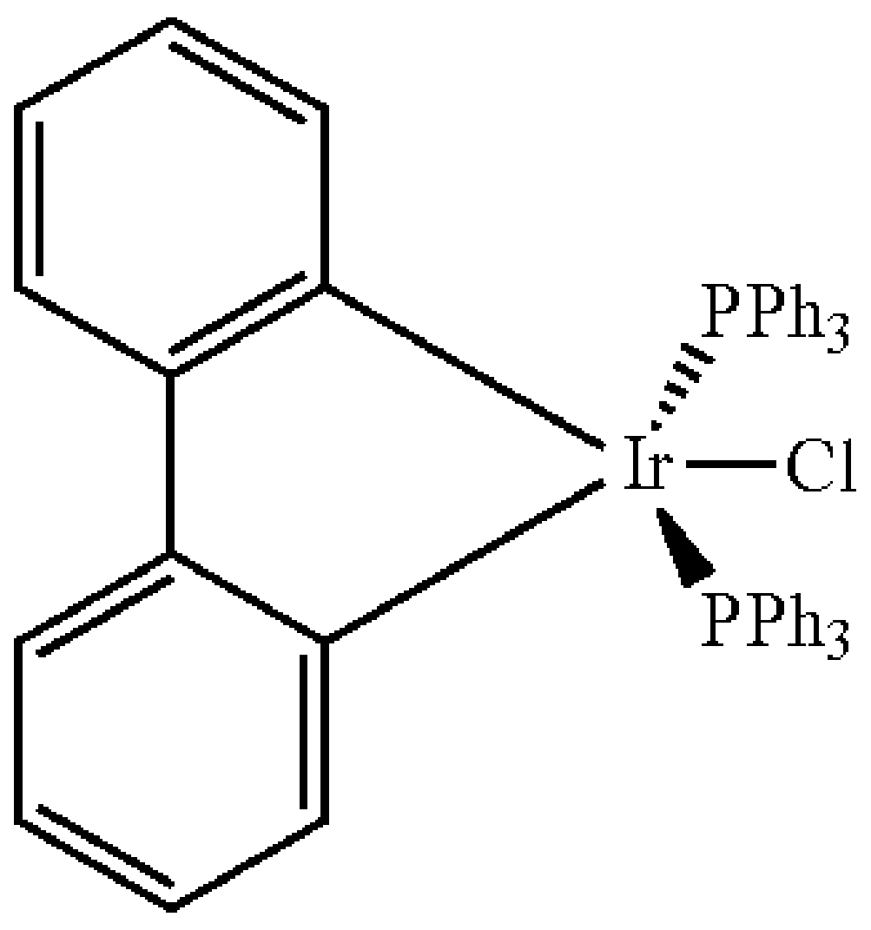
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		US20070087321
		Adv. Mater. 19, 739 (2007)
		WO2009100991
		WO2008101842
		U.S. Pat. No. 7,232,618

TABLE 4-continued

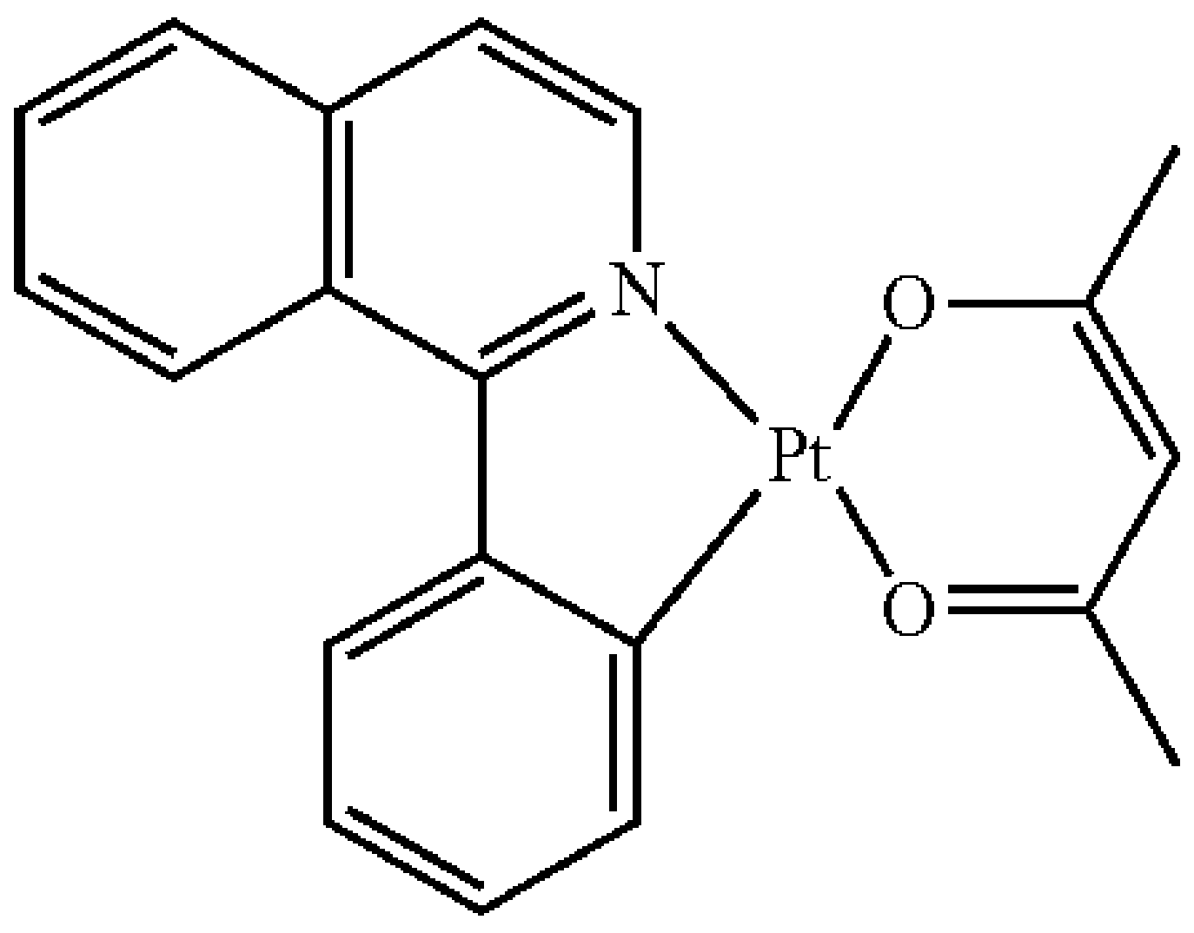
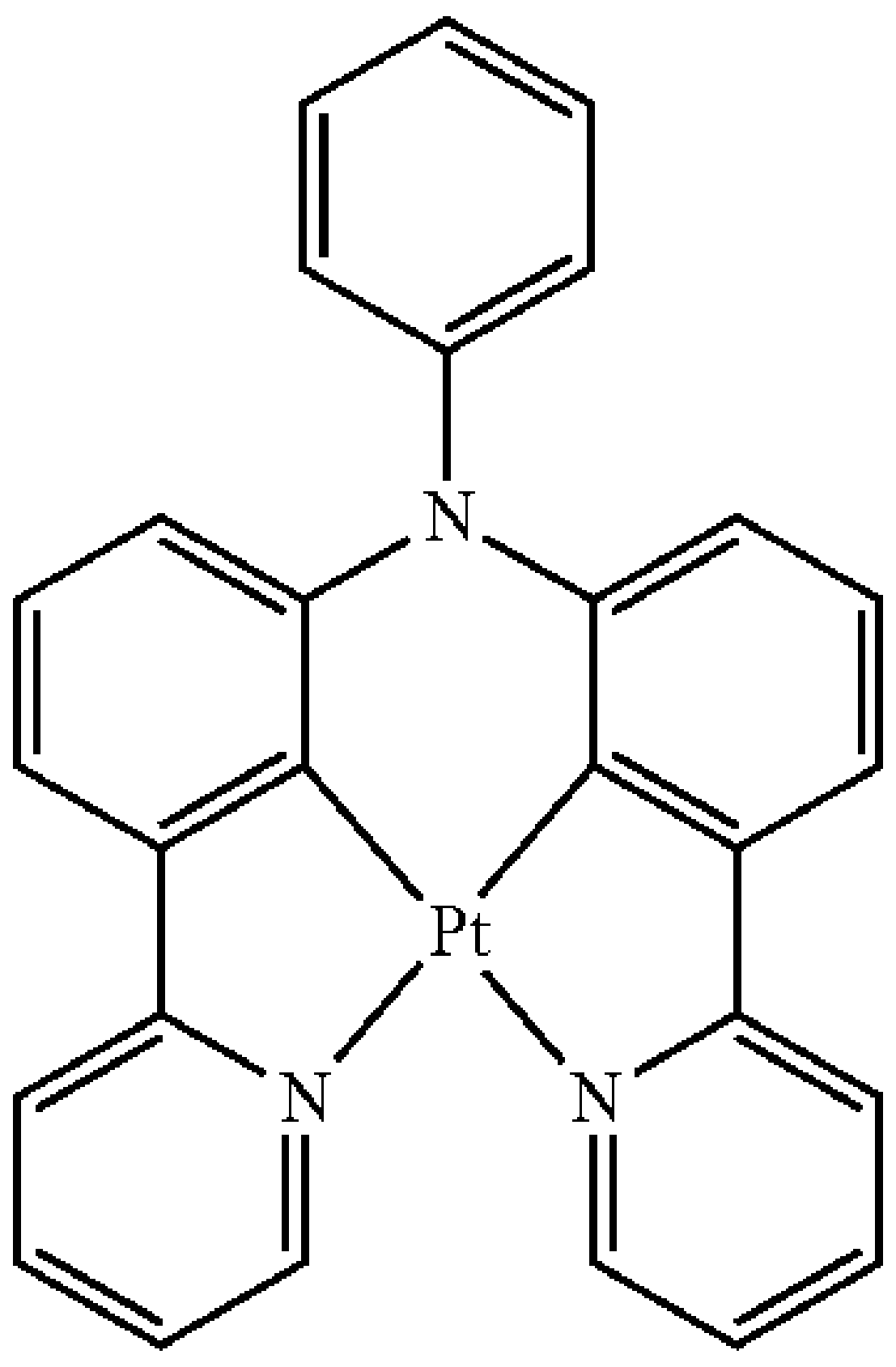
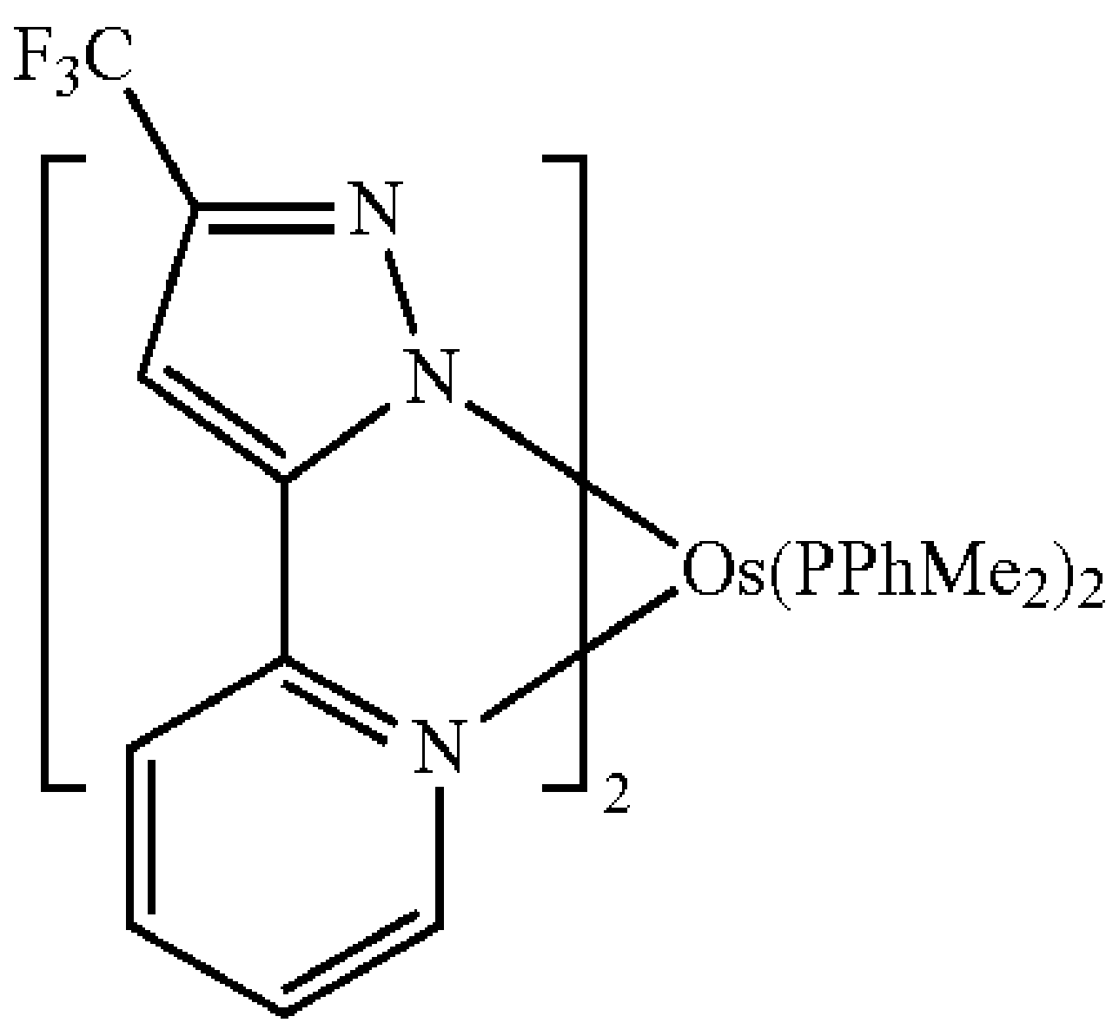
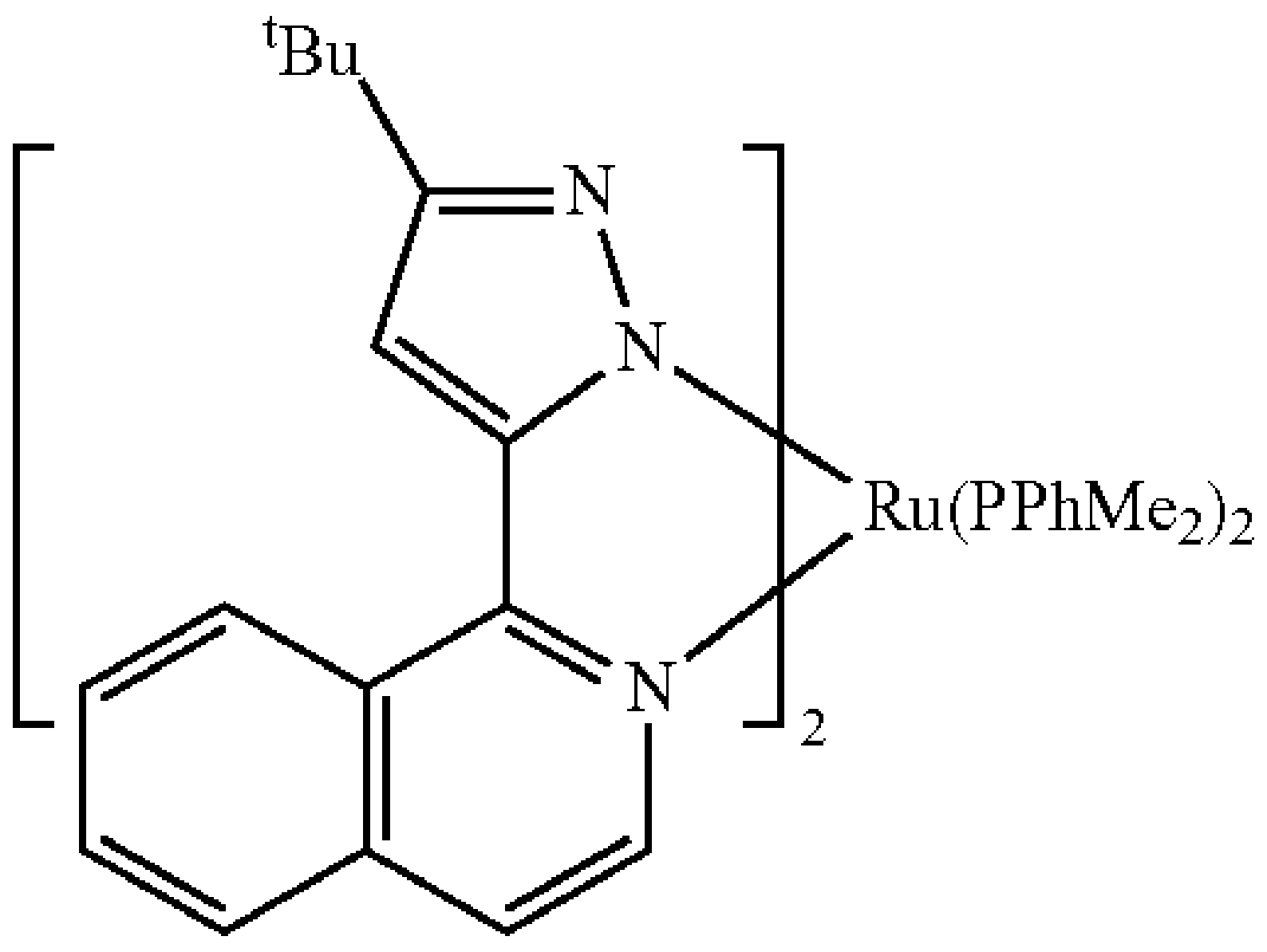
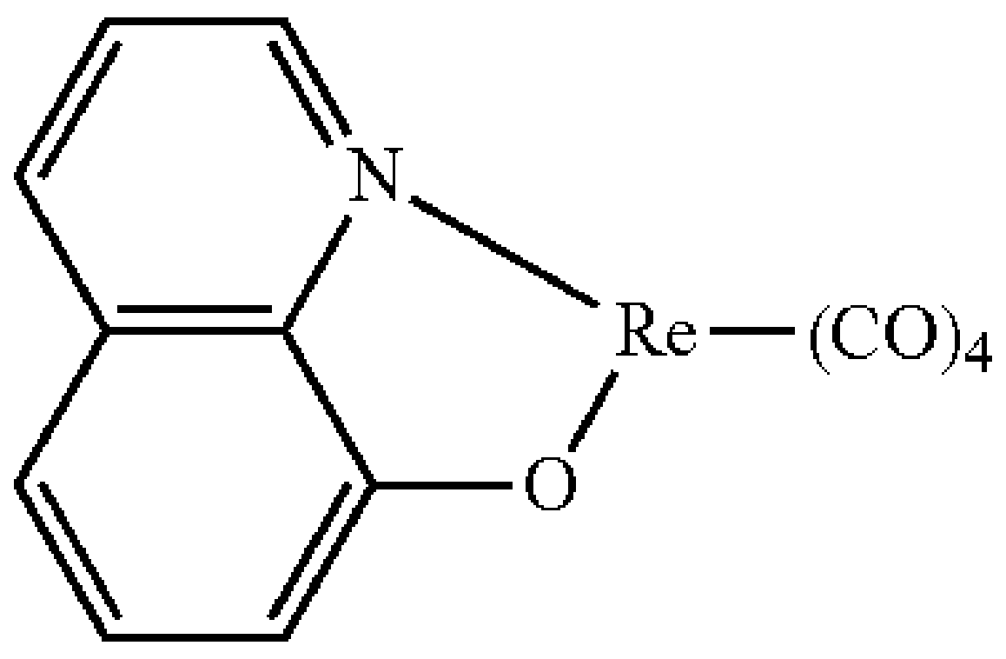
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
Platinum(II) organometallic complexes		WO2003040257
		US20070103060
Osminum(III) complexes		Chem. Mater. 17, 3532 (2005)
Ruthenium(II) complexes		Adv. Mater. 17, 1059 (2005)
Rhenium (I), (II), and (III) complexes		US20050244673

TABLE 4-continued

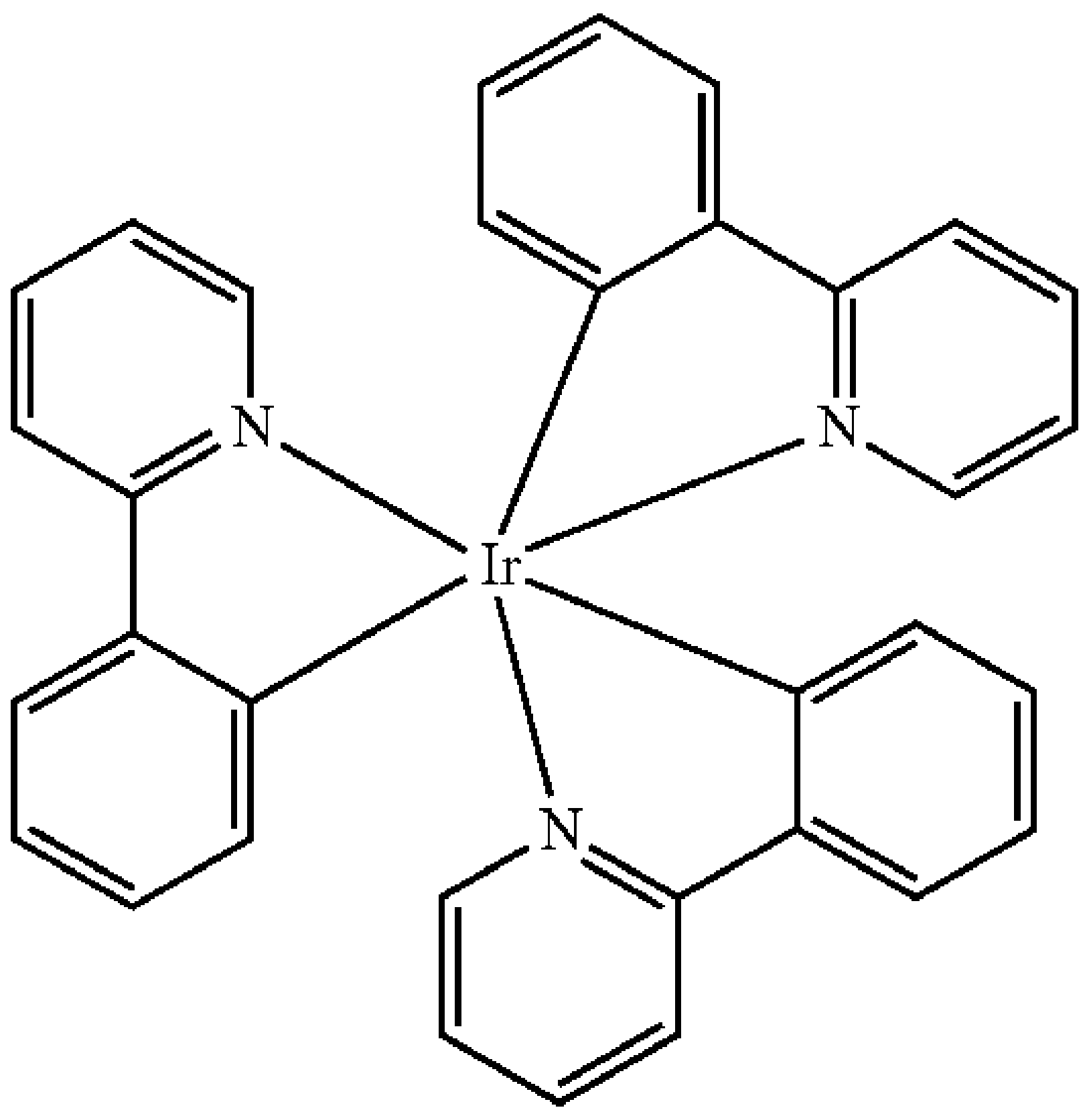
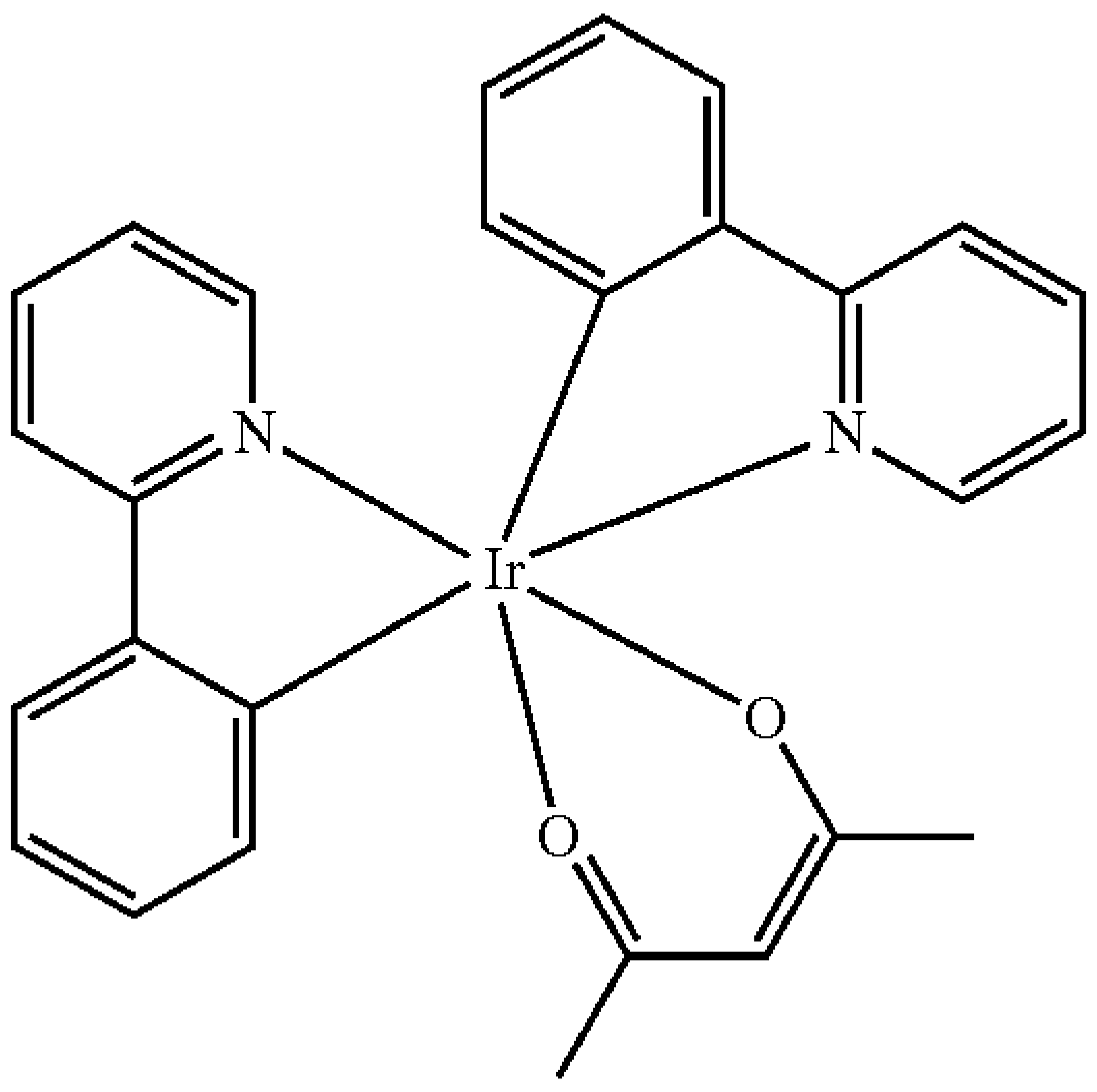
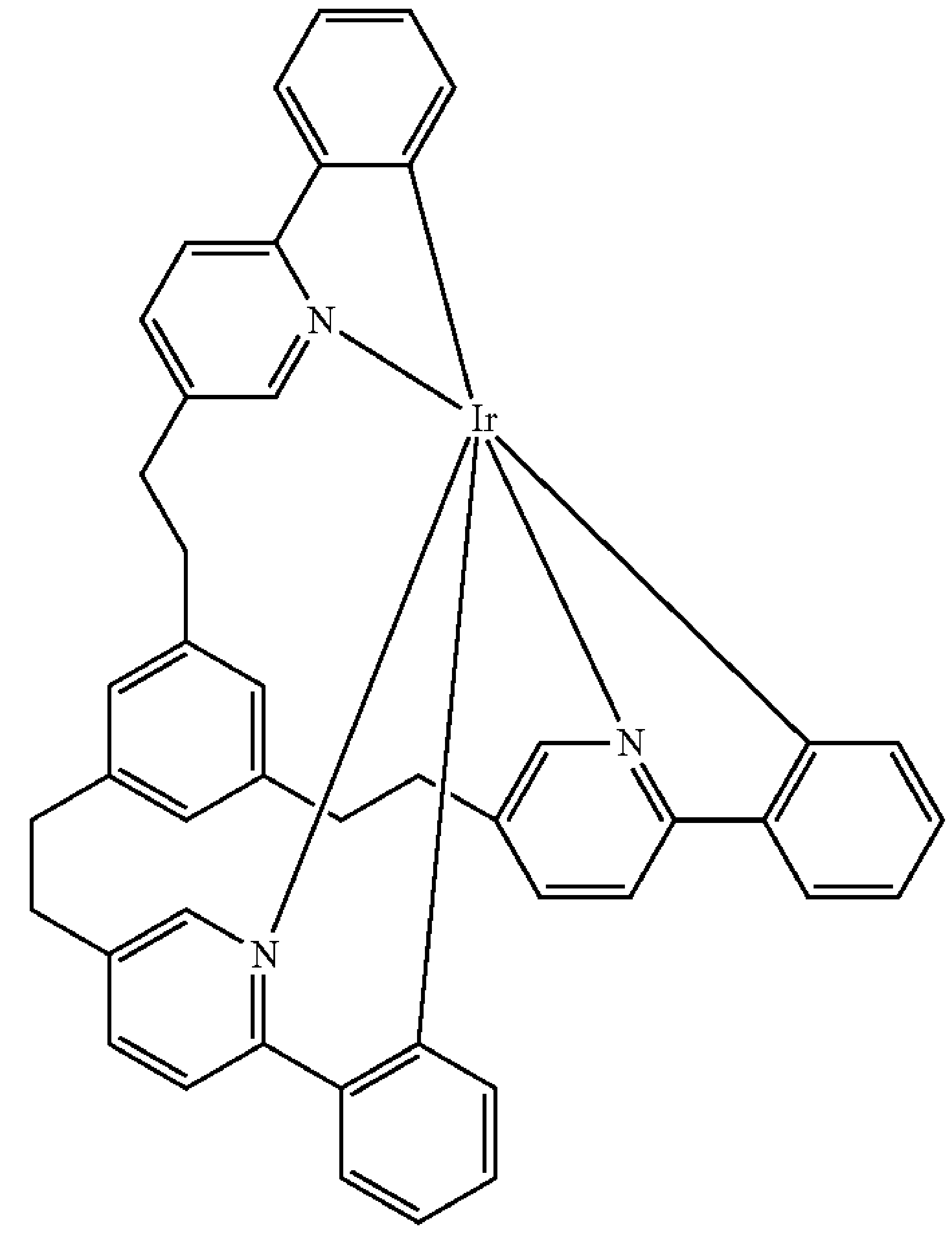
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
	Green dopants	
Iridium(III) organometallic complexes	 and its derivatives	Inorg. Chem. 40, 1704 (2001)
		US20020034656
		U.S. Pat. No. 7,332,232

TABLE 4-continued

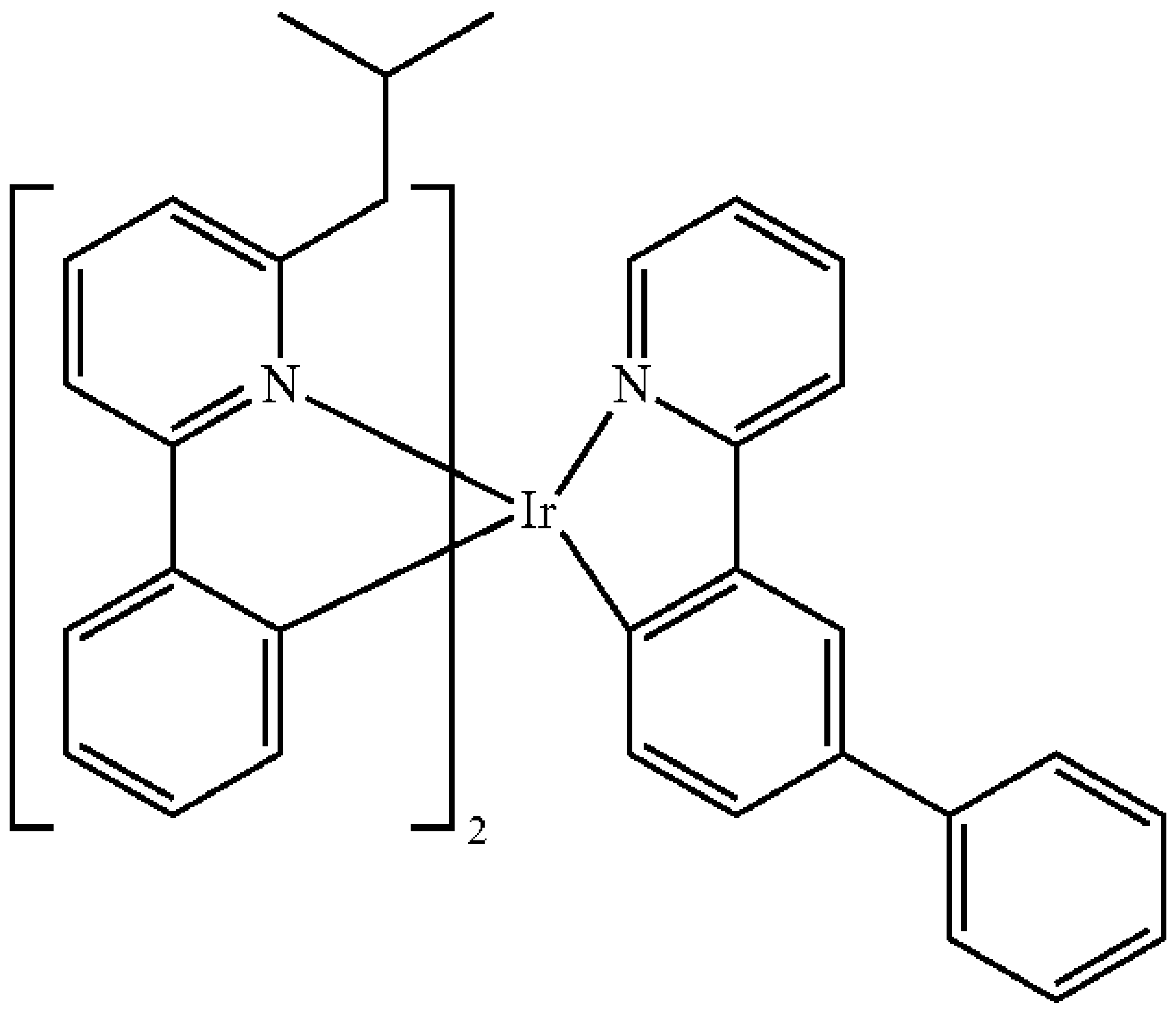
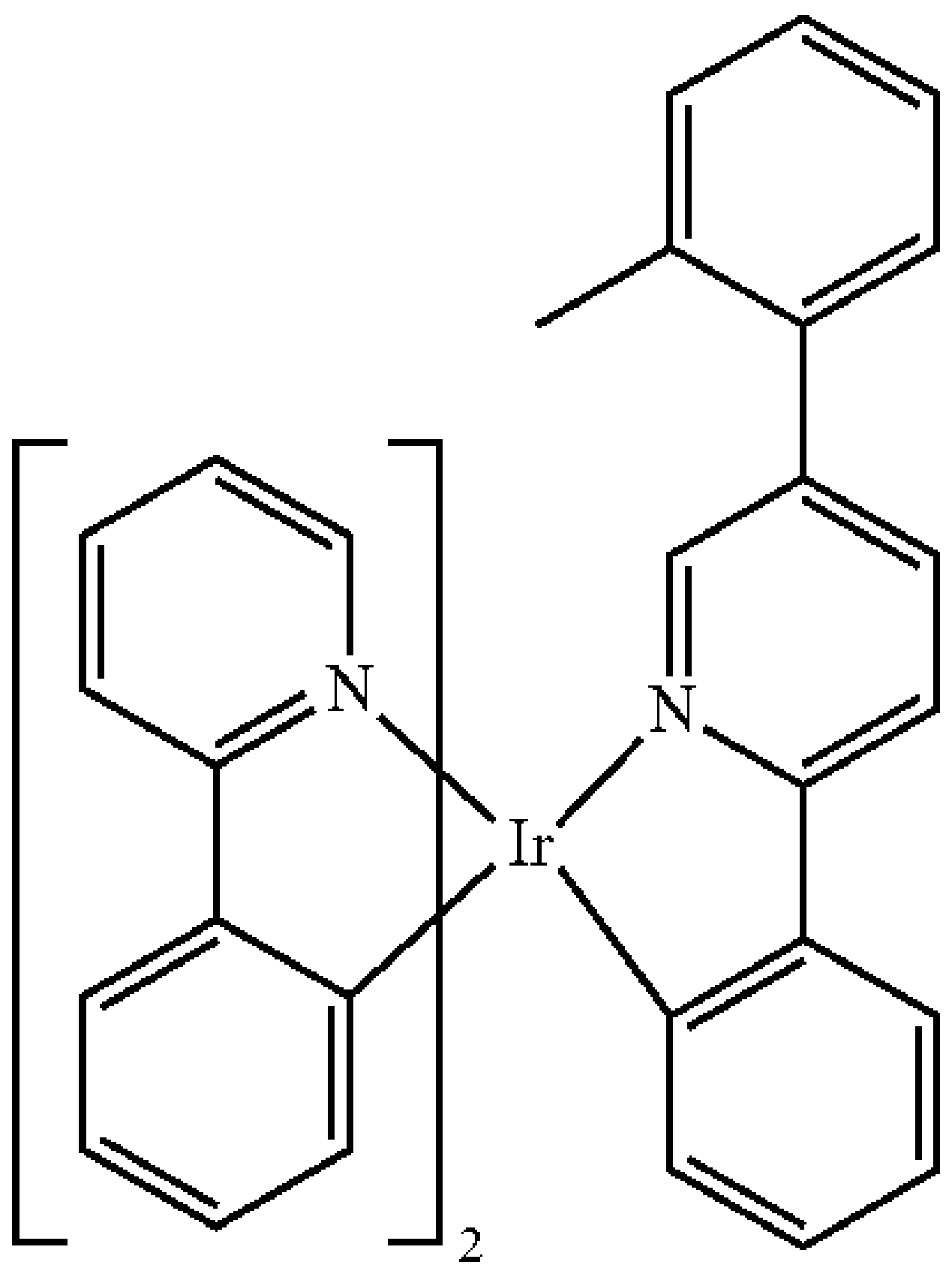
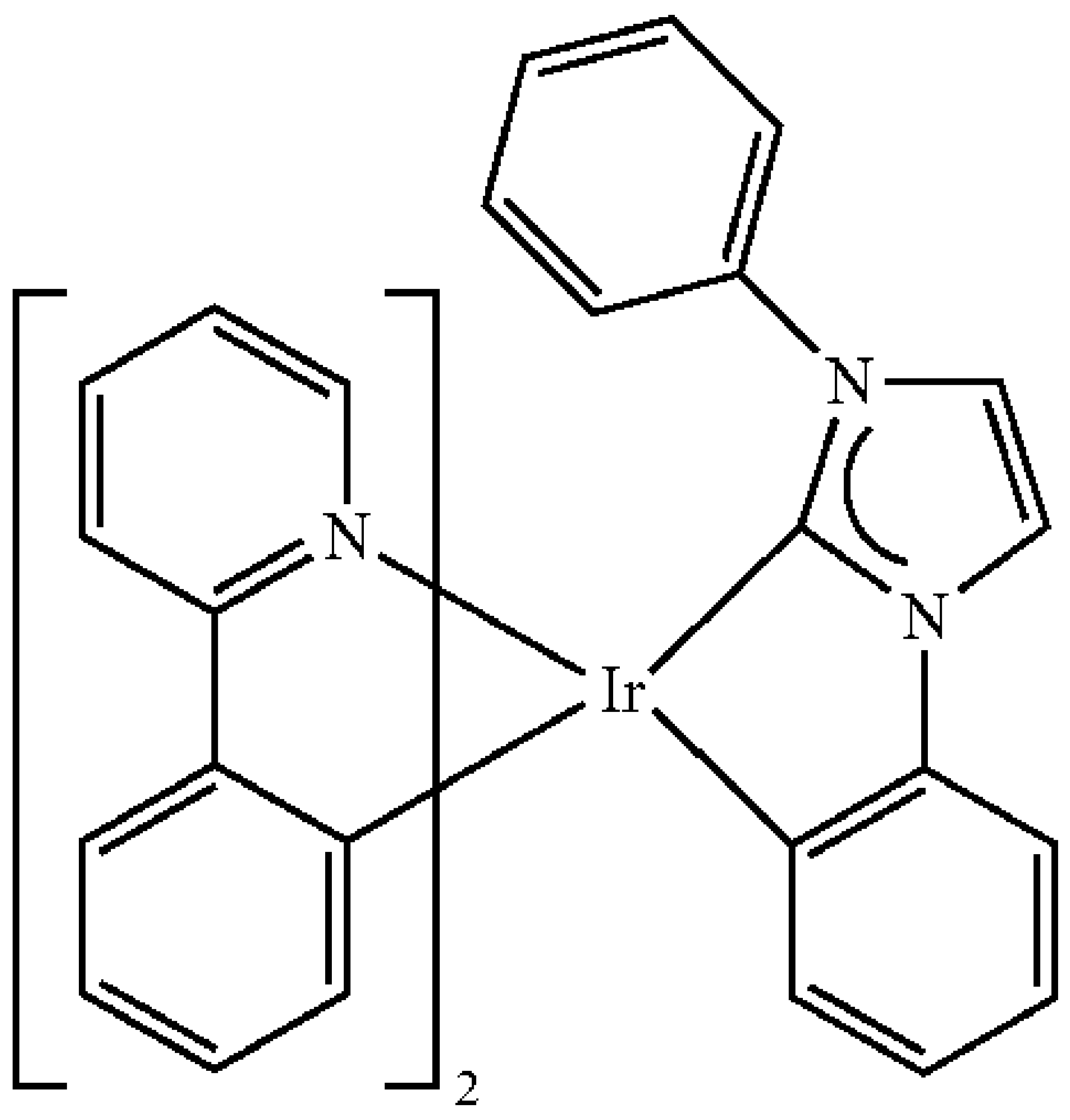
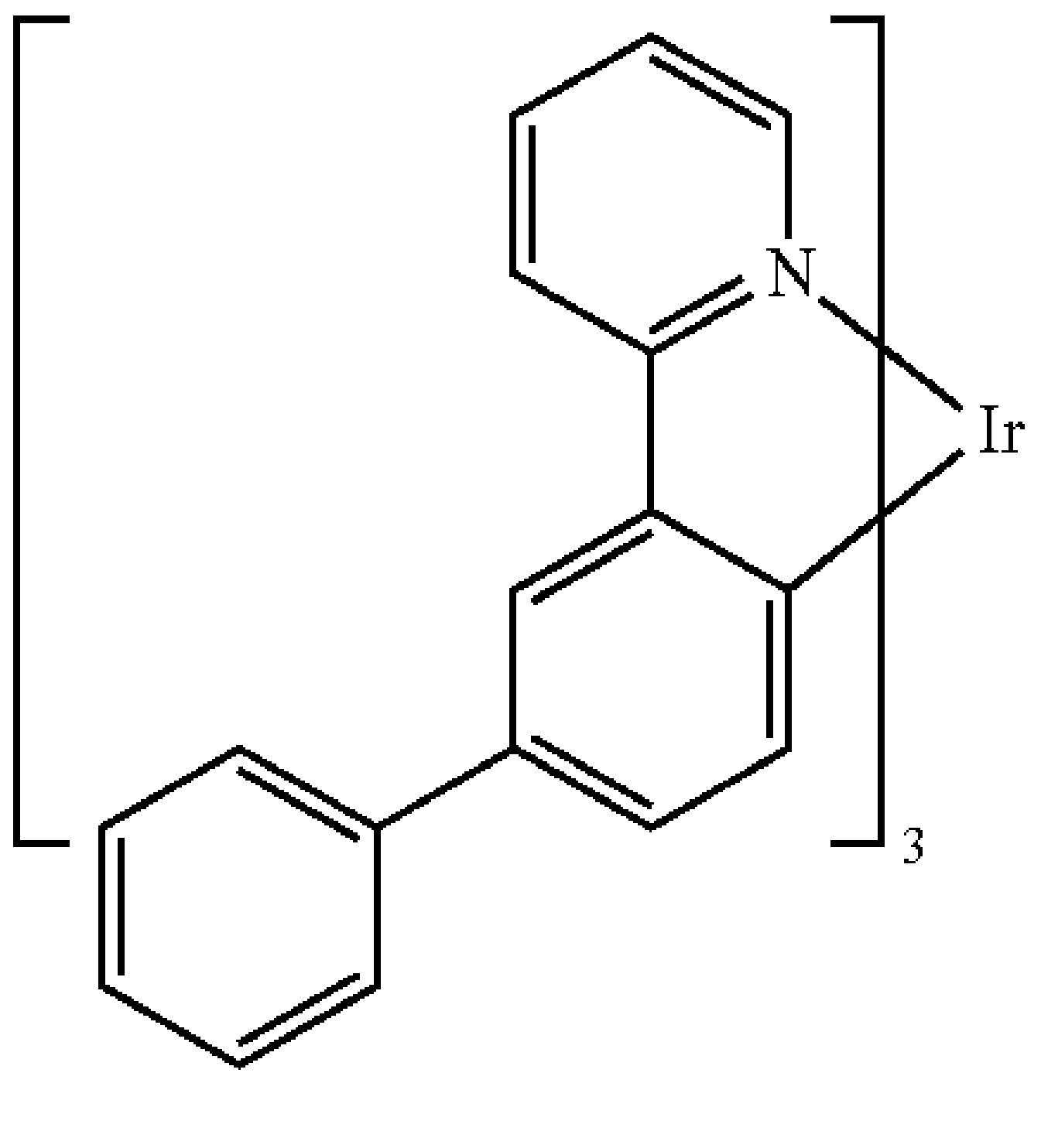
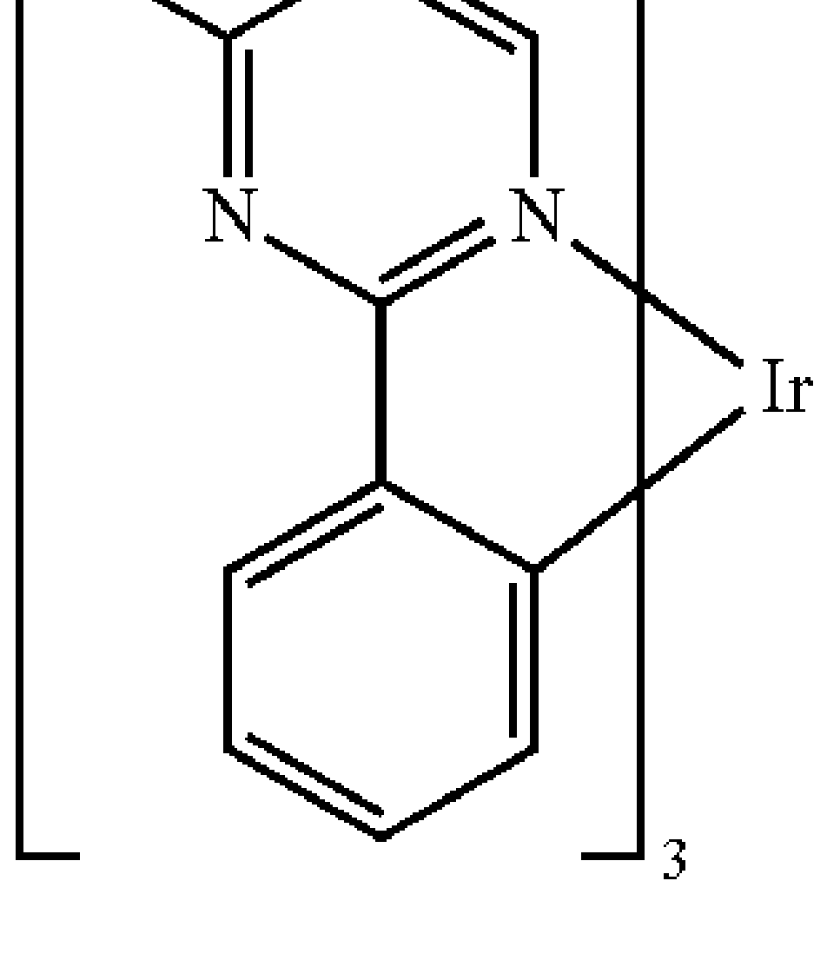
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20090108737
		WO2010028151
		EP1841834B
		US20060127696
		US20090039776

TABLE 4-continued

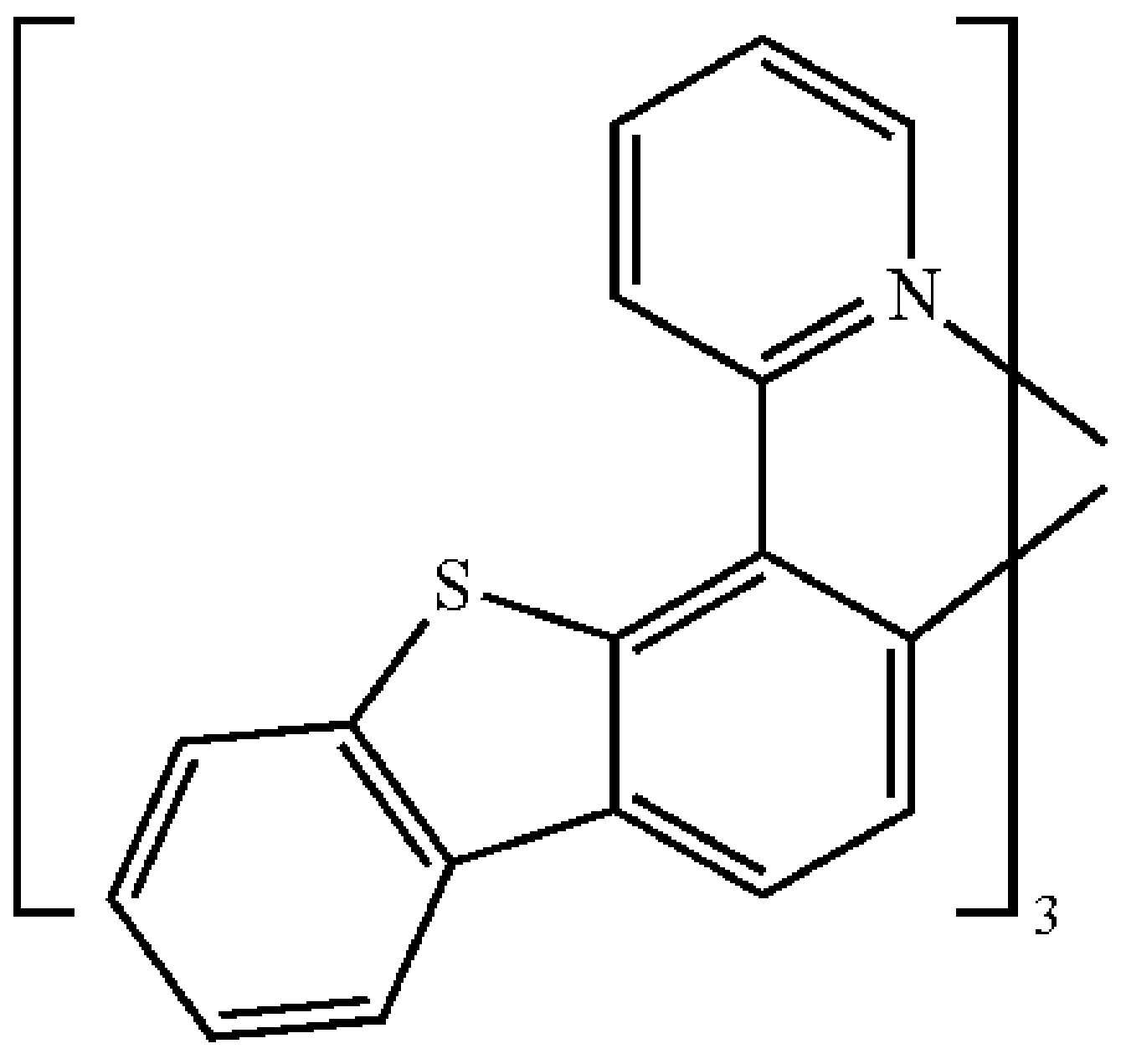
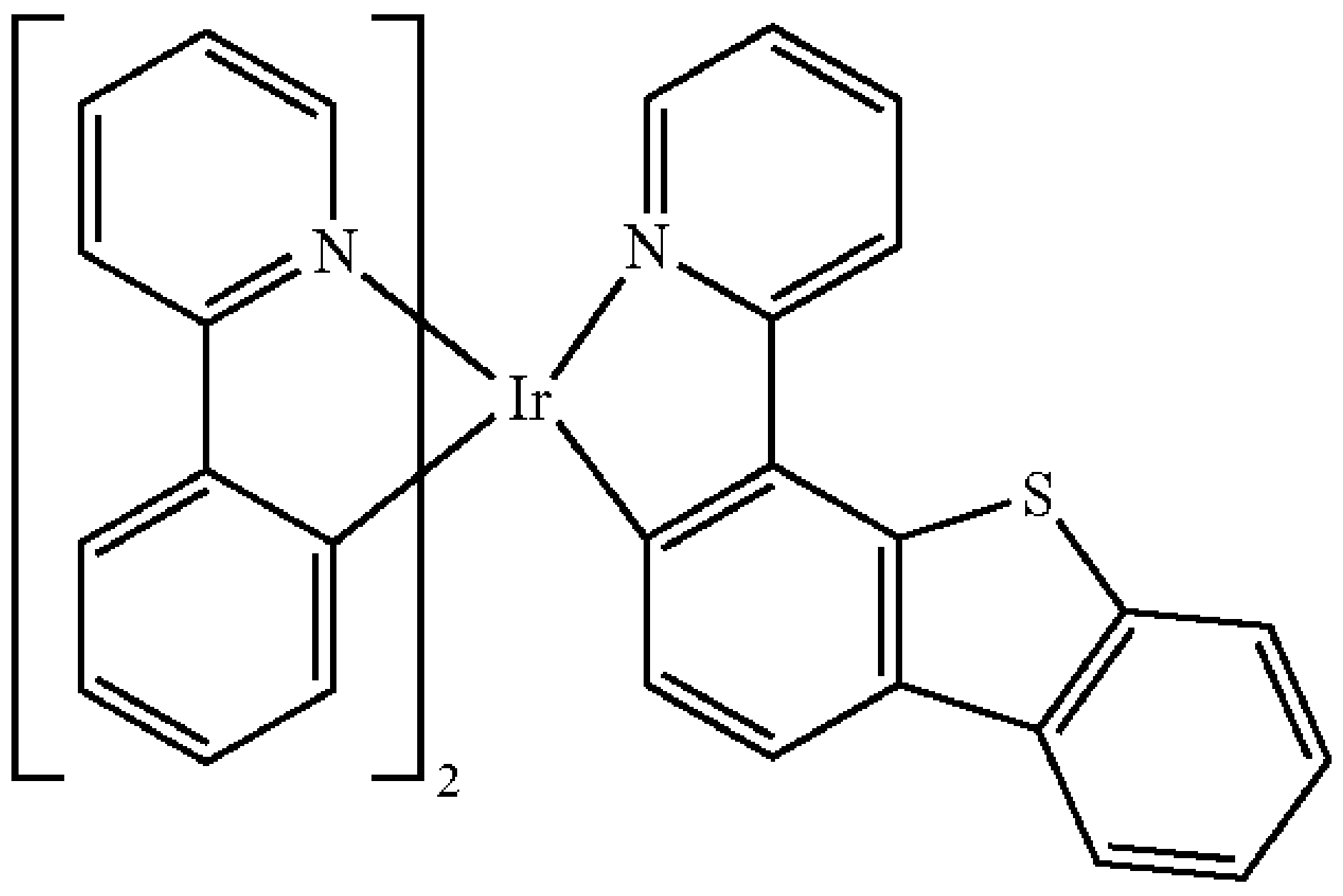
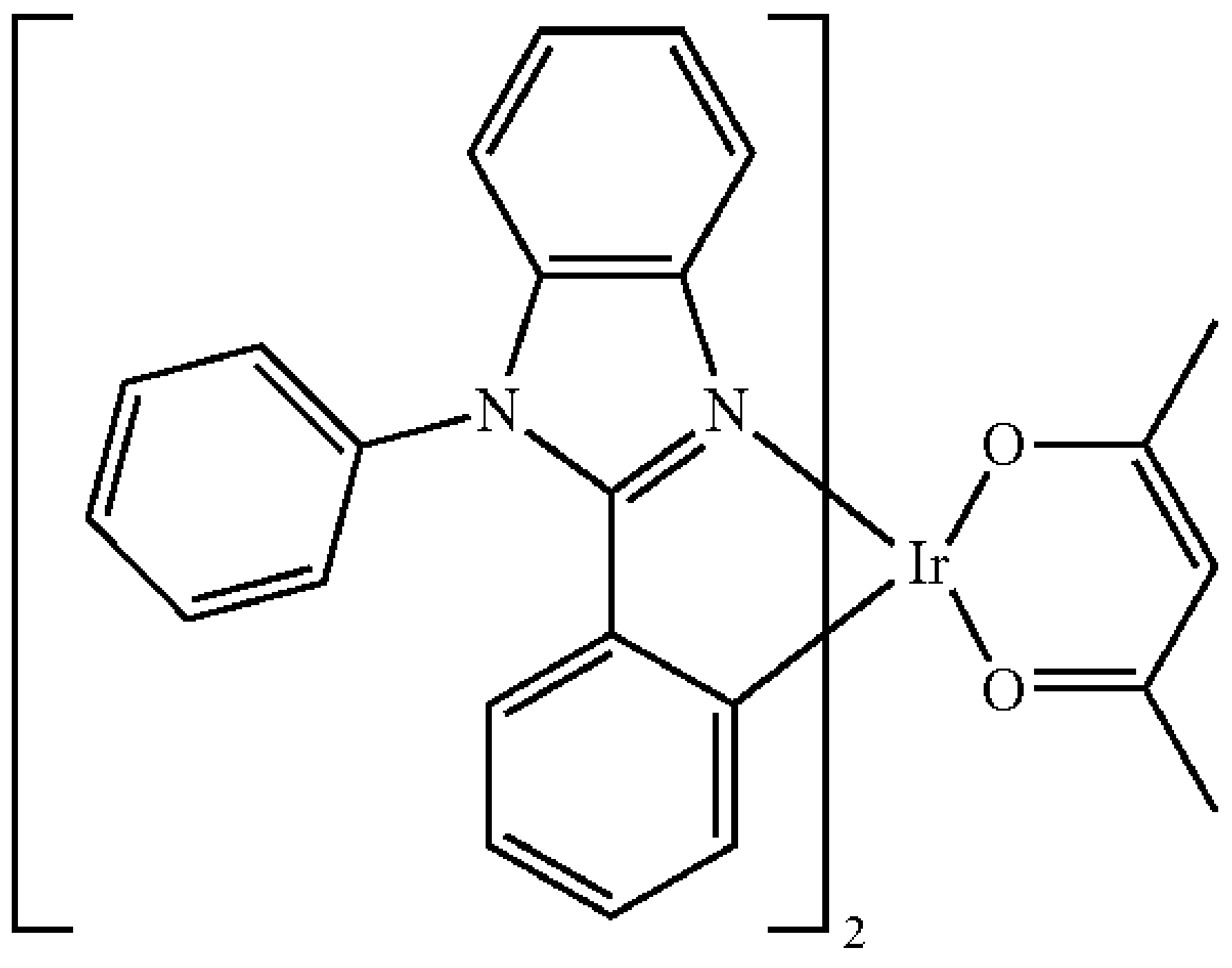
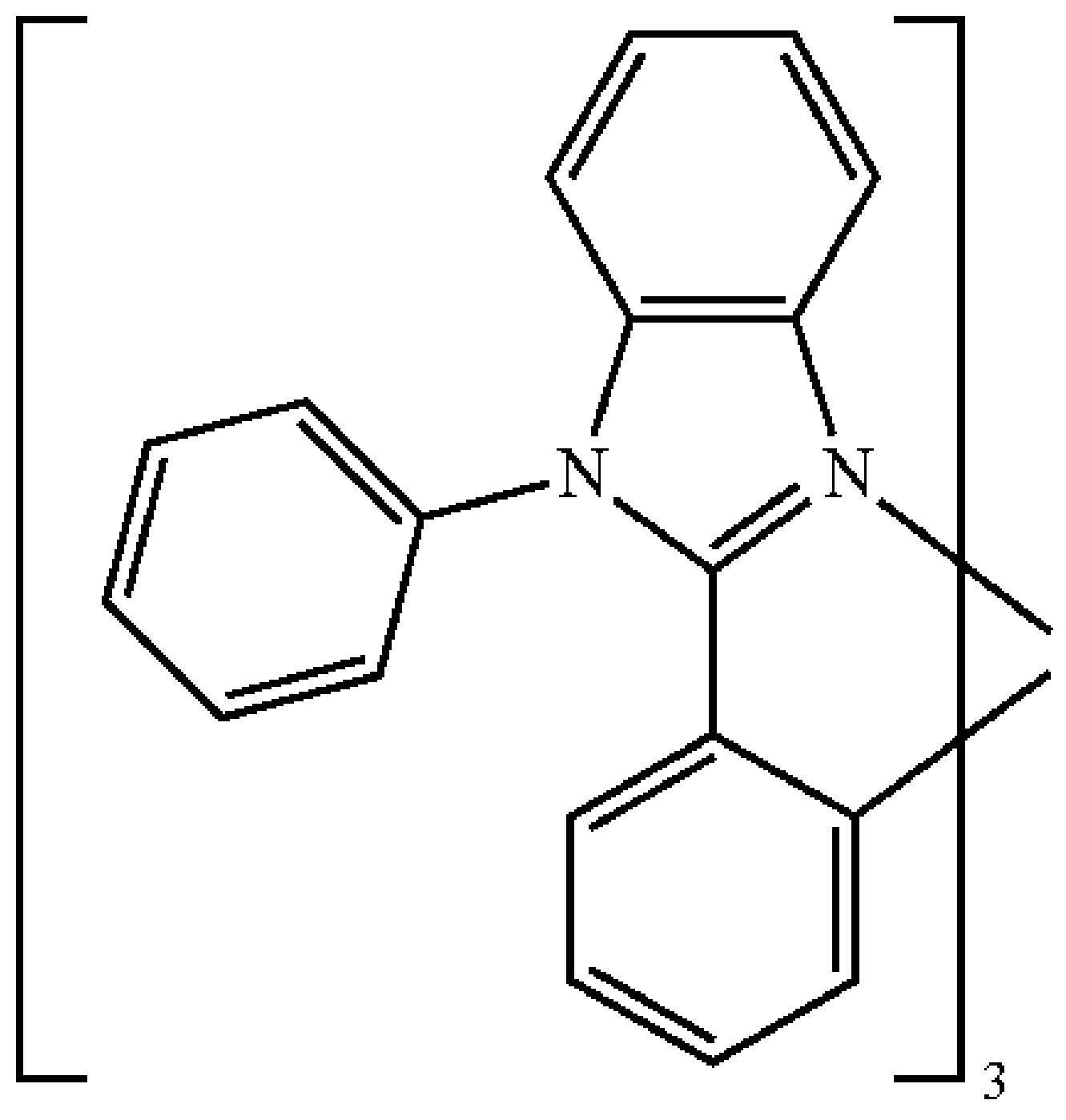
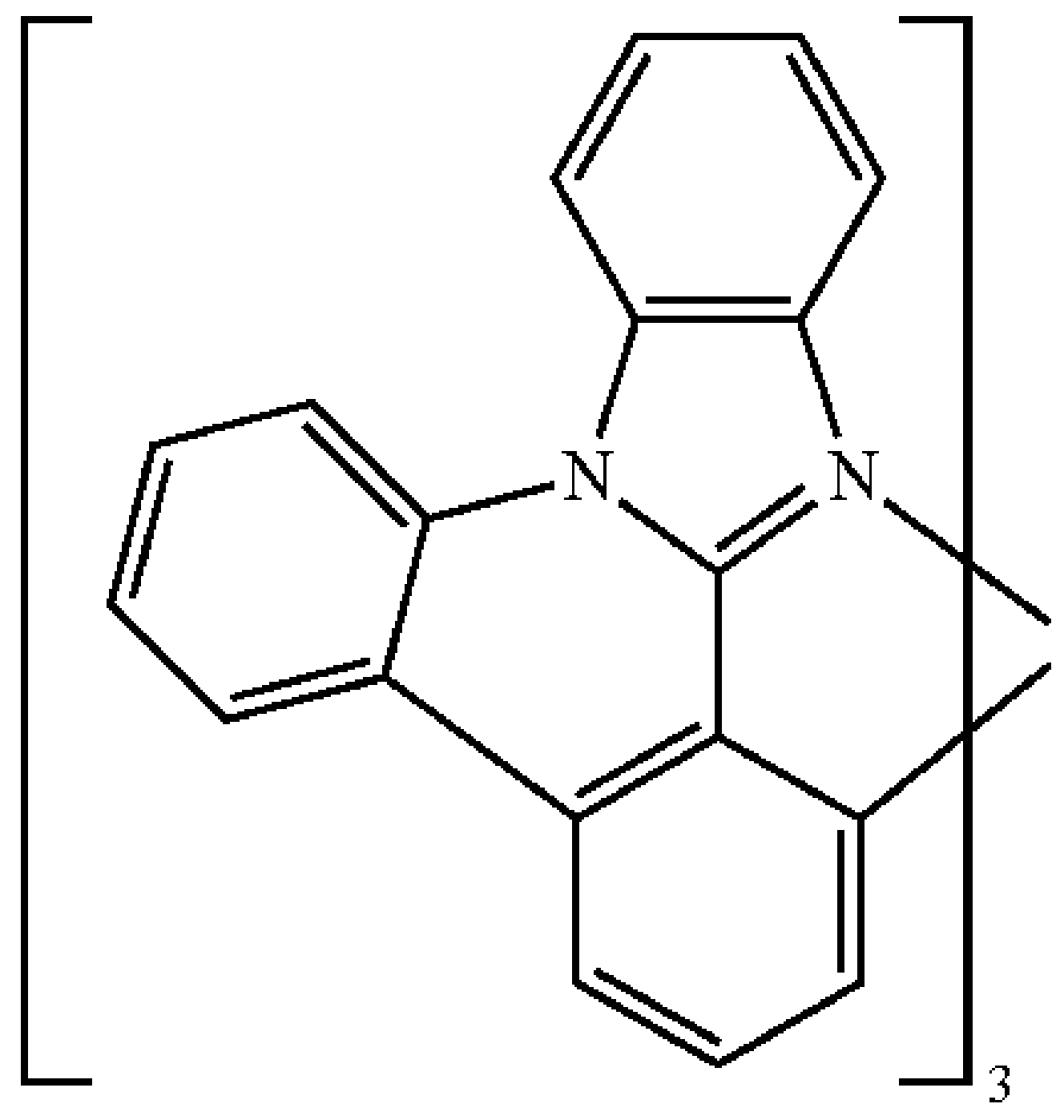
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		U.S. Pat. No. 6,921,915
		US20100244004
		U.S. Pat. No. 6,687,266
		Chem. Mater. 16, 2480 (2004)
		US20070190359

TABLE 4-continued

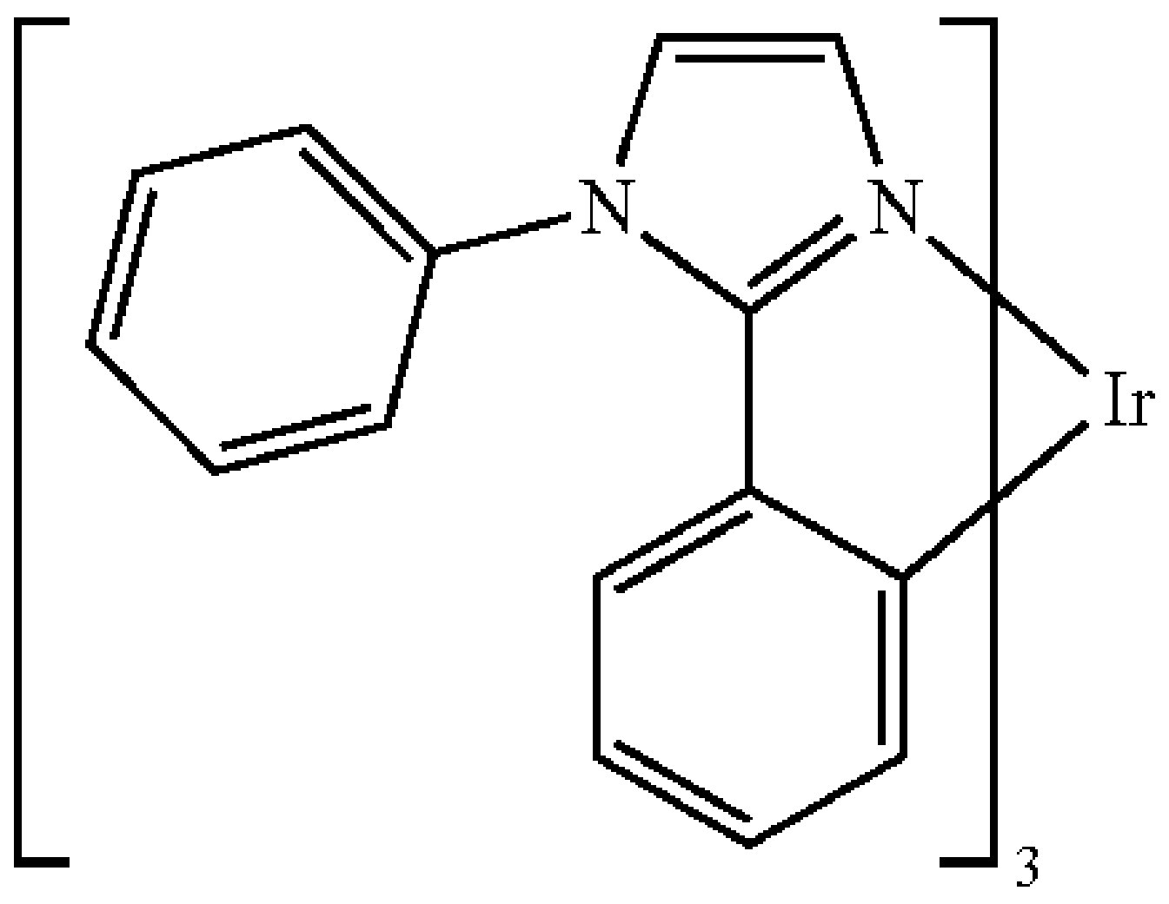
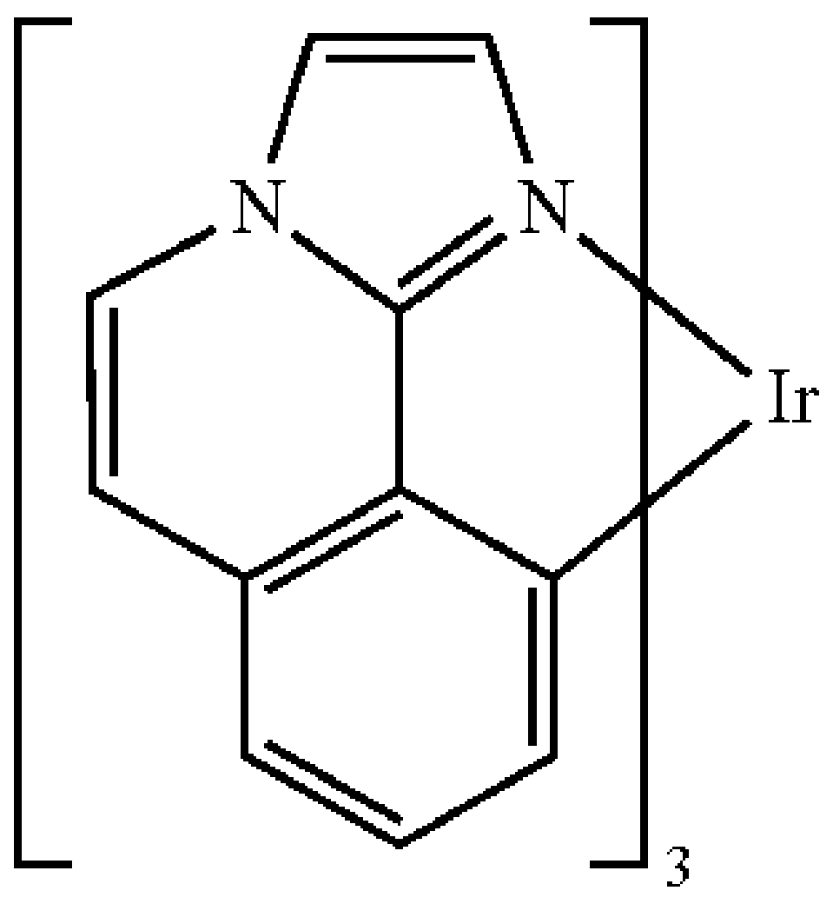
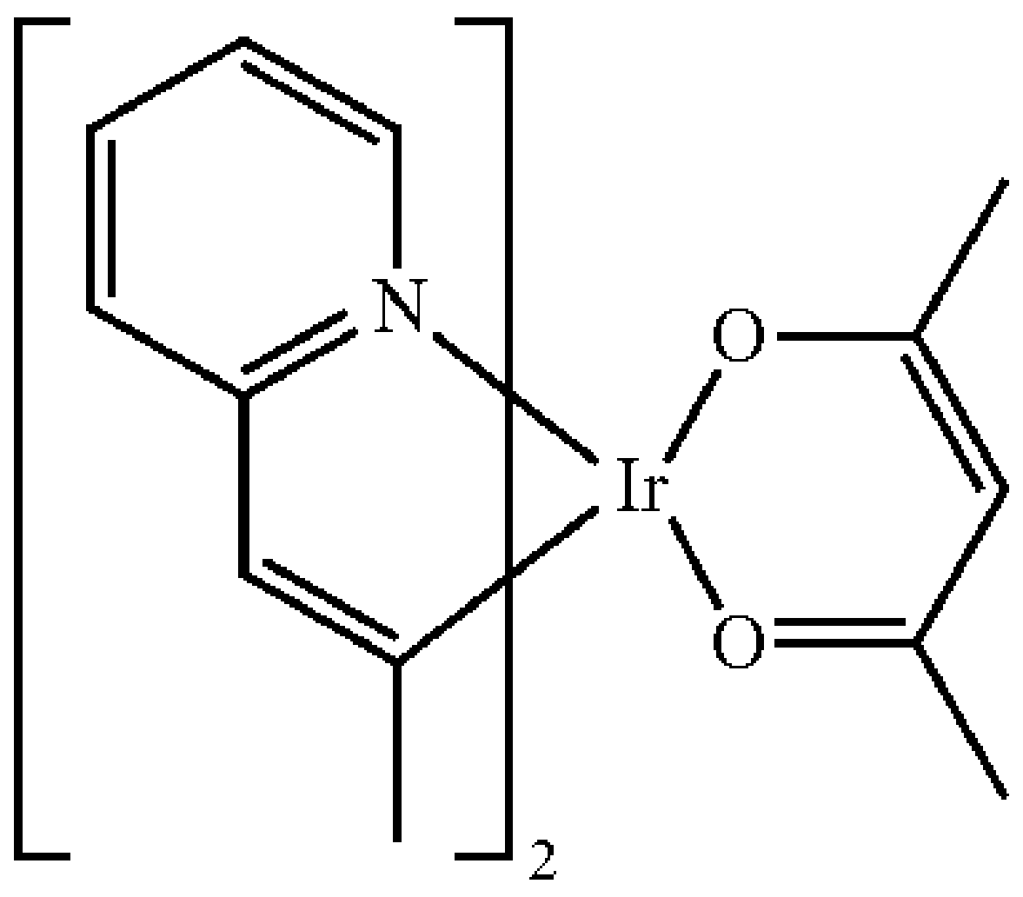
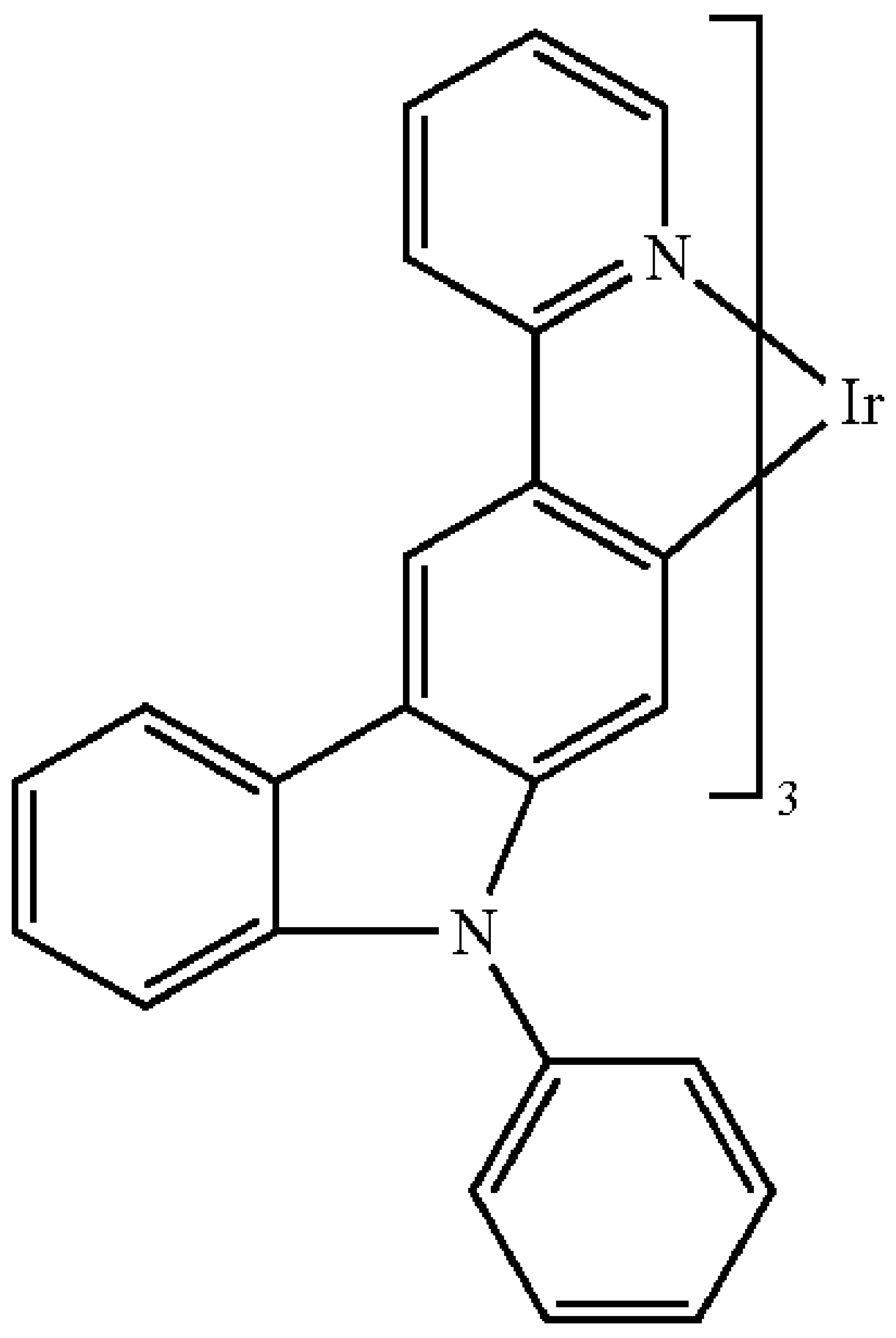
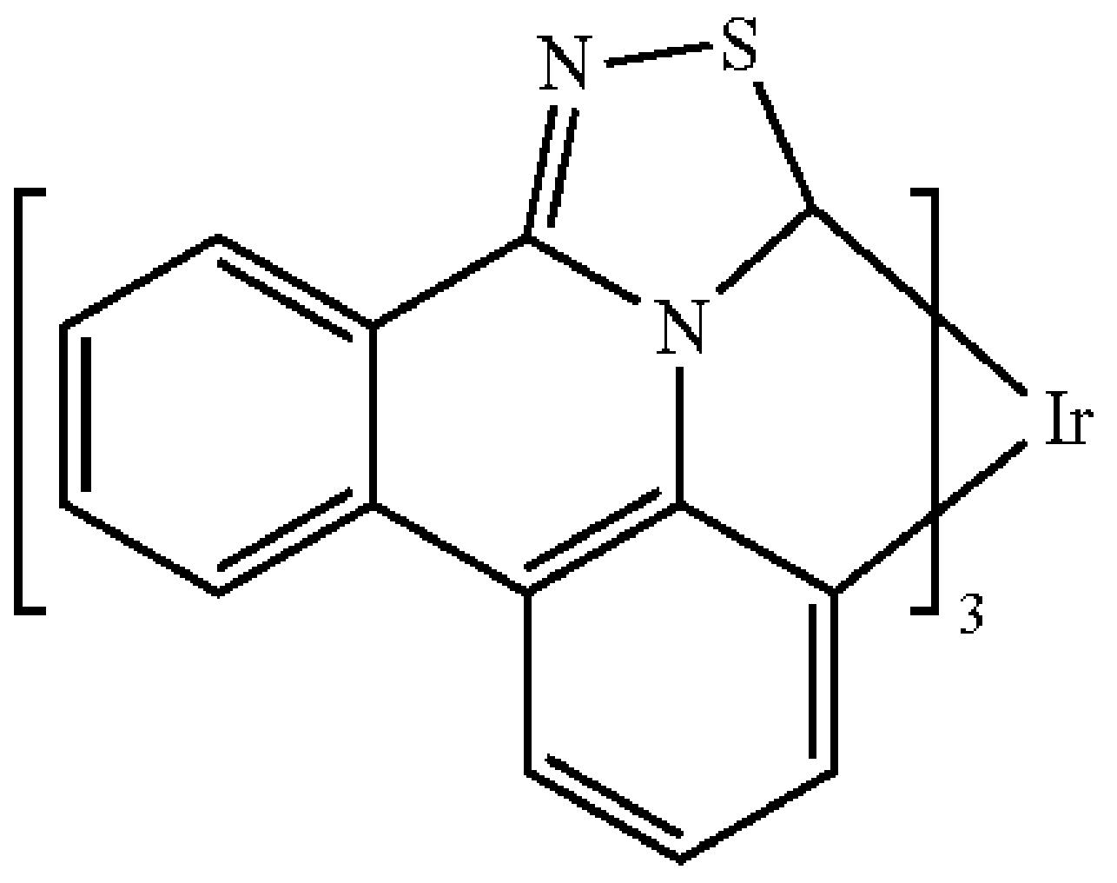
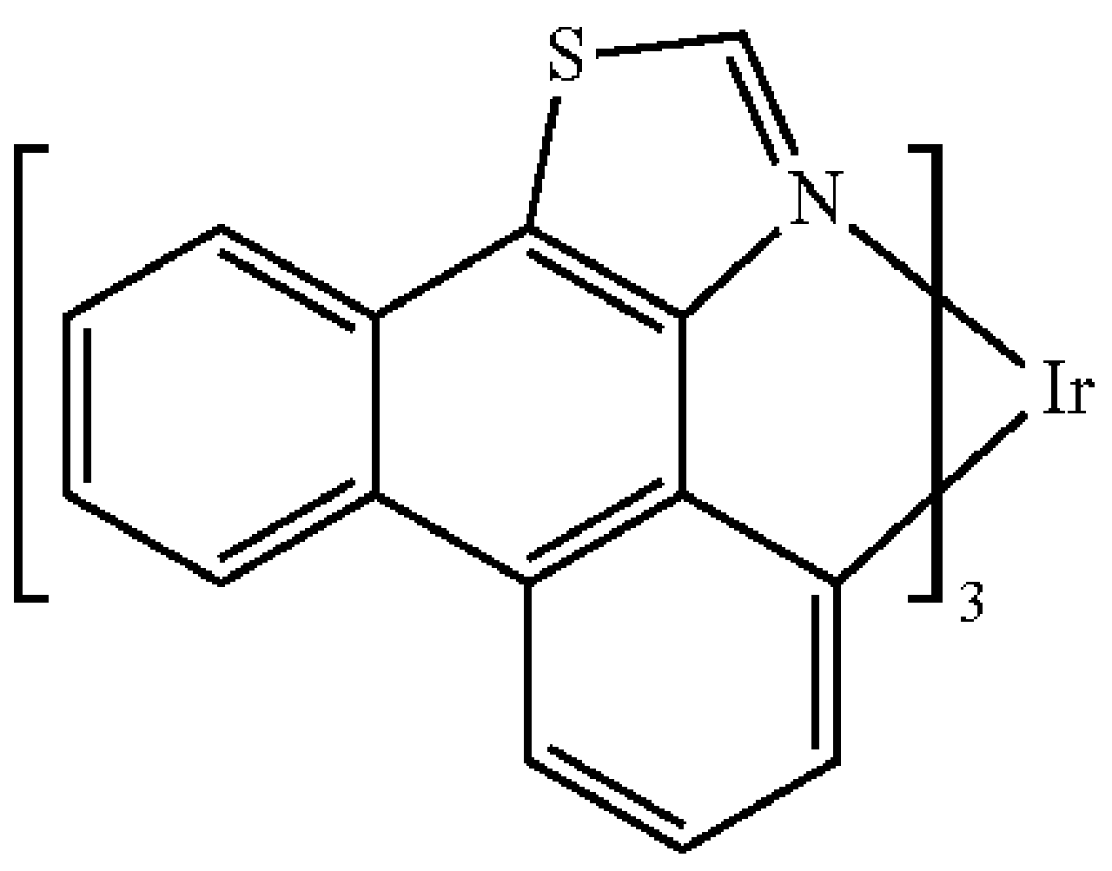
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		US 20060008670 JP2007123392
		WO2010086089, WO2011044988
		Adv. Mater. 16, 2003 (2004)
		Angew. Chem. Int. Ed. 2006, 45, 7800
		WO2009050290
		US20090165846

TABLE 4-continued

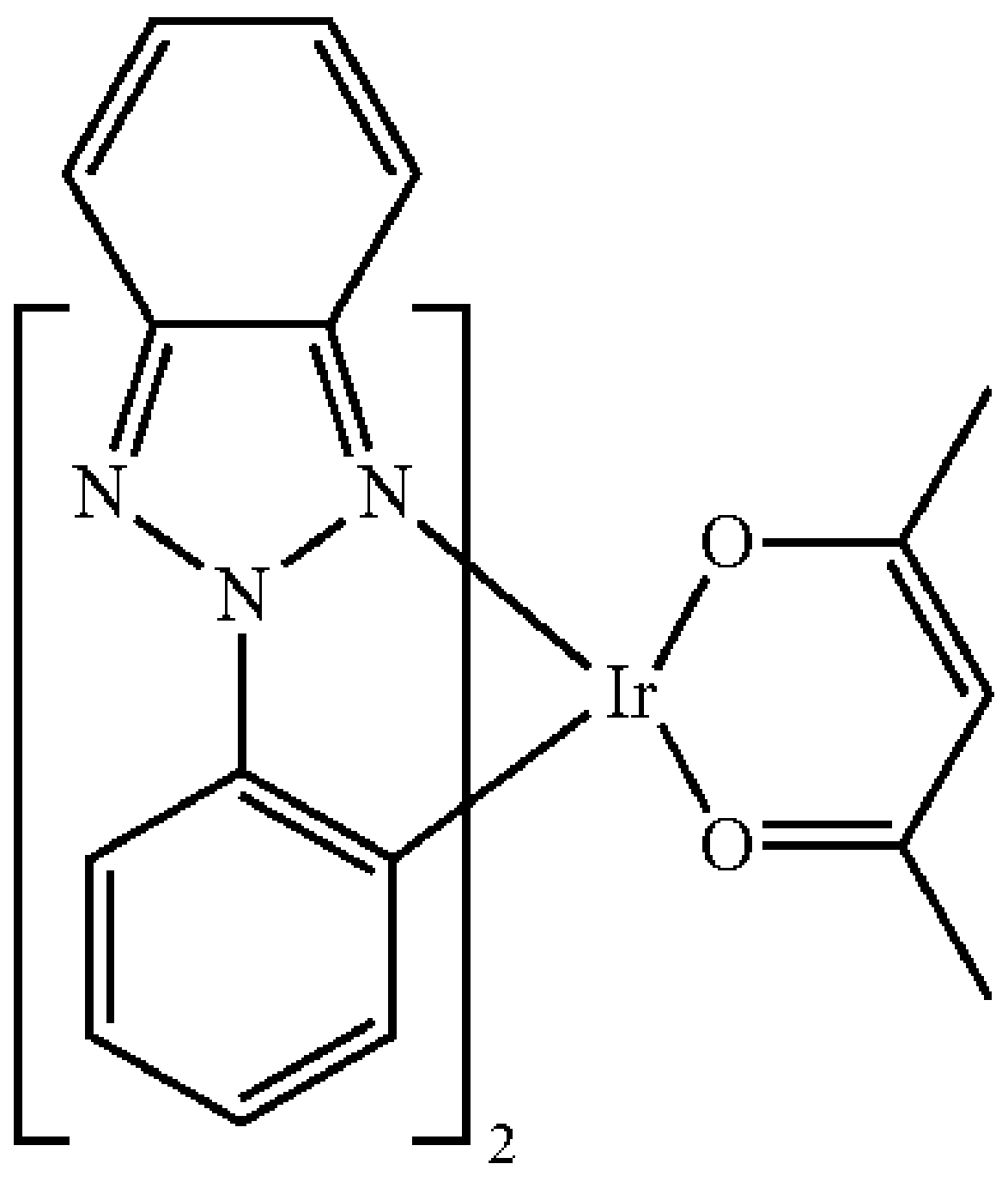
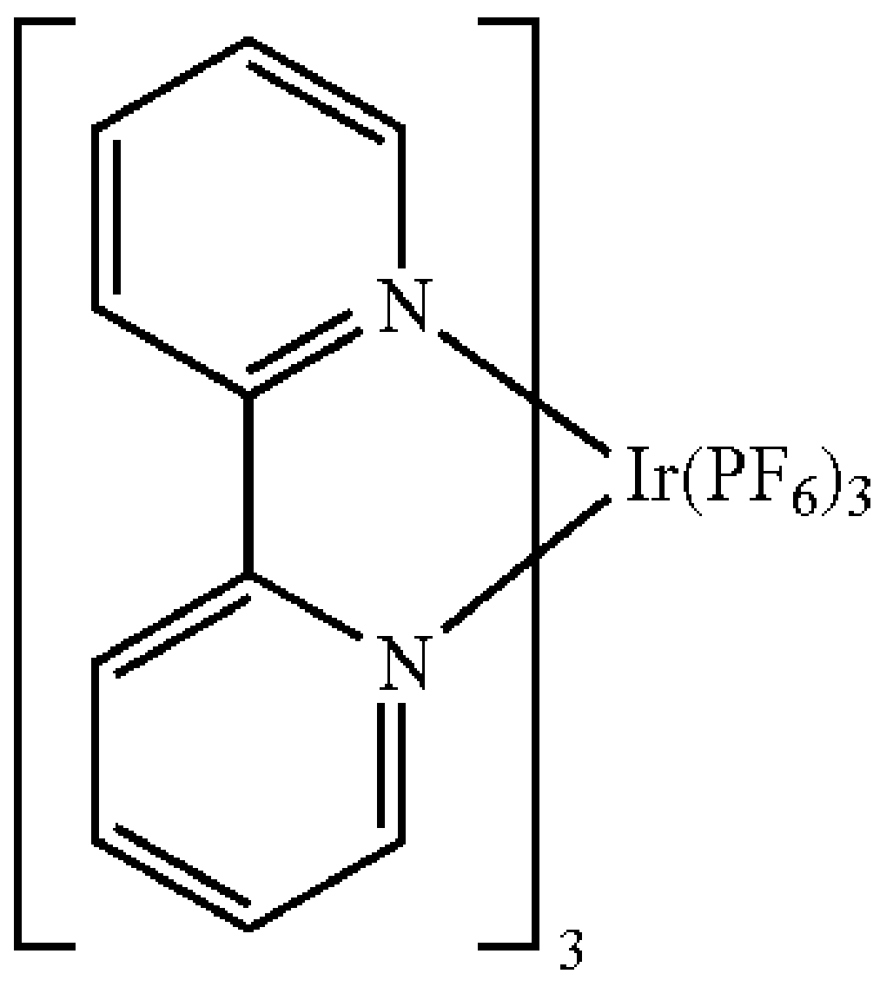
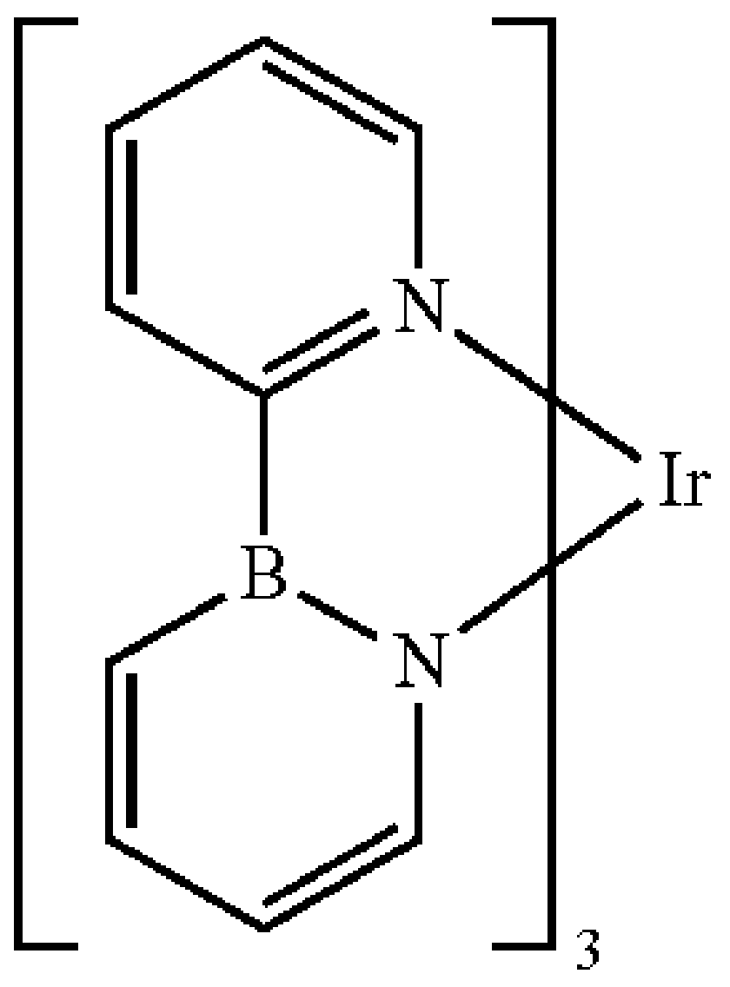
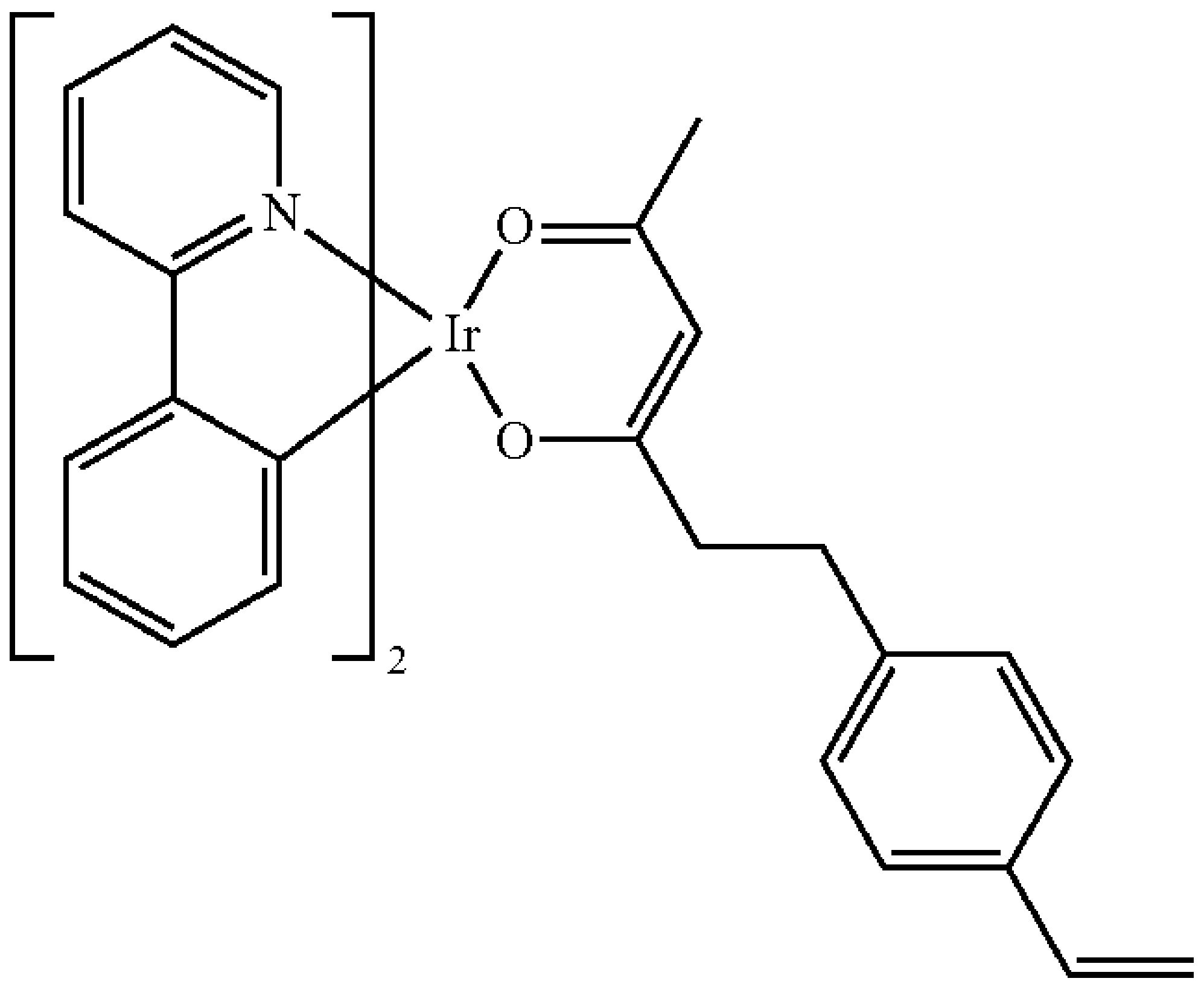
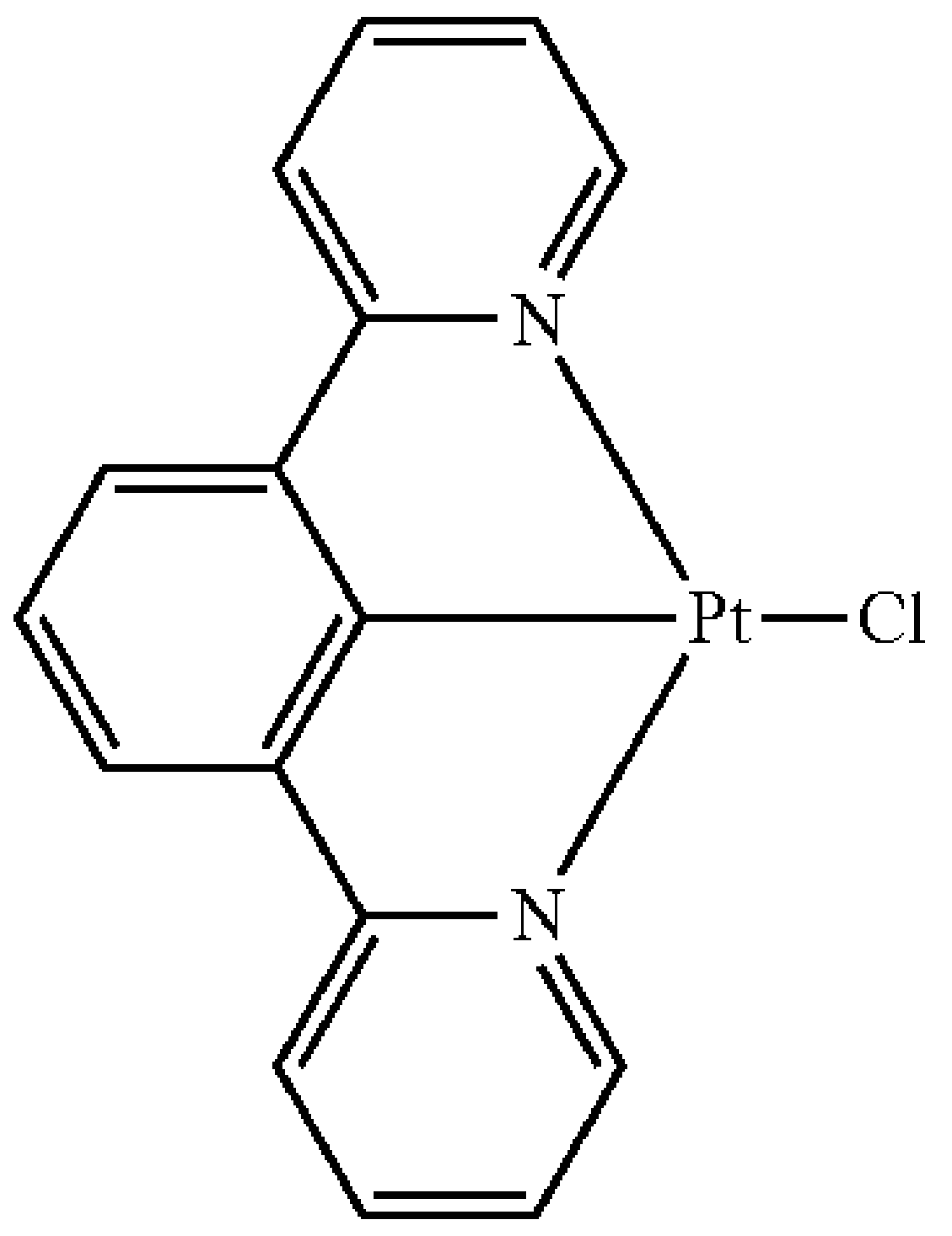
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		US20080015355
		US20010015432
		US20100295032
Monomer for polymeric metal organometallic compounds		U.S. Pat. No. 7,250,226, U.S. Pat. No. 7,396,598
Pt(II) organometallic complexes, including polydentated ligands		Appl. Phys. Lett. 86, 153505 (2005)

TABLE 4-continued

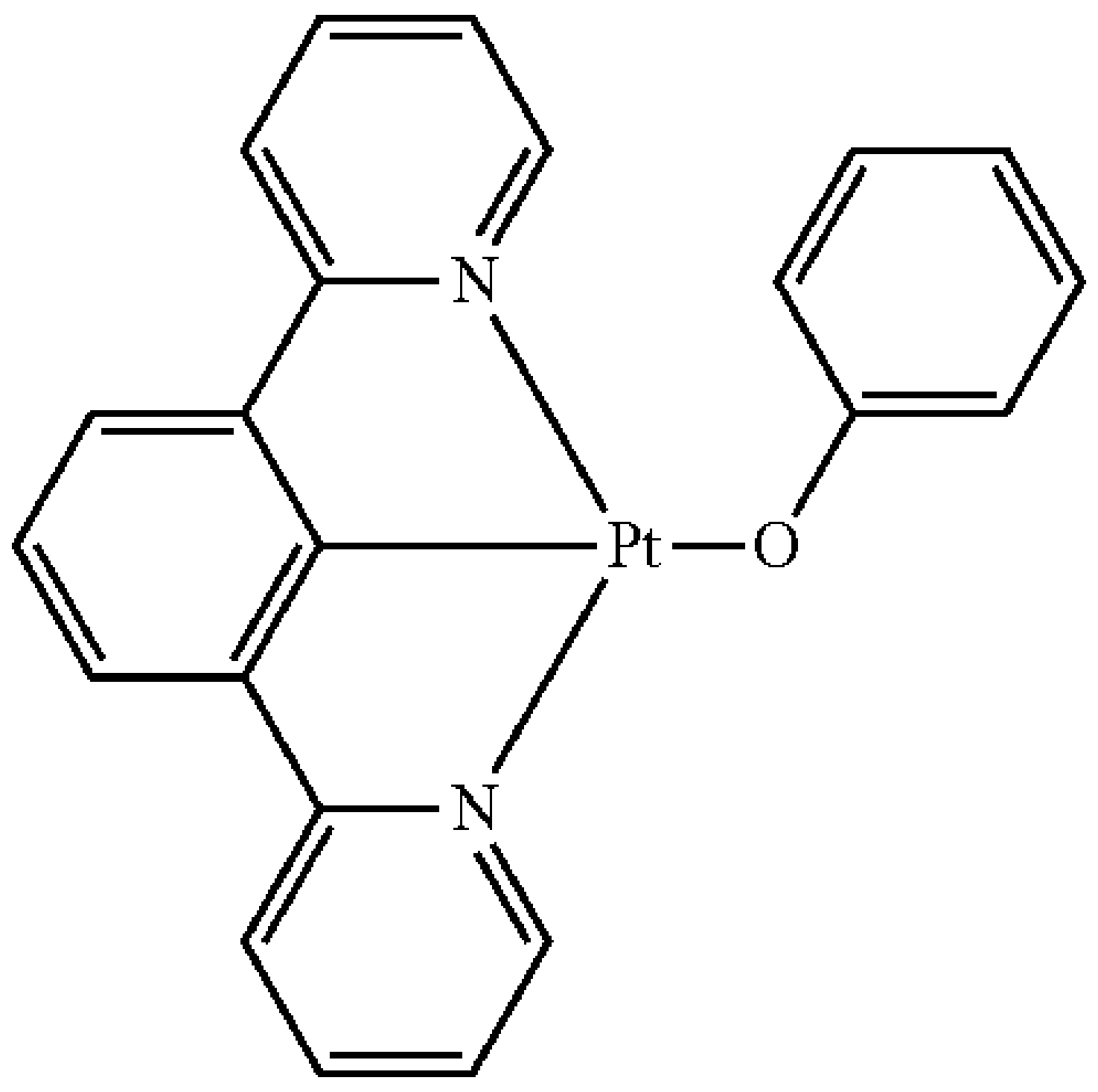
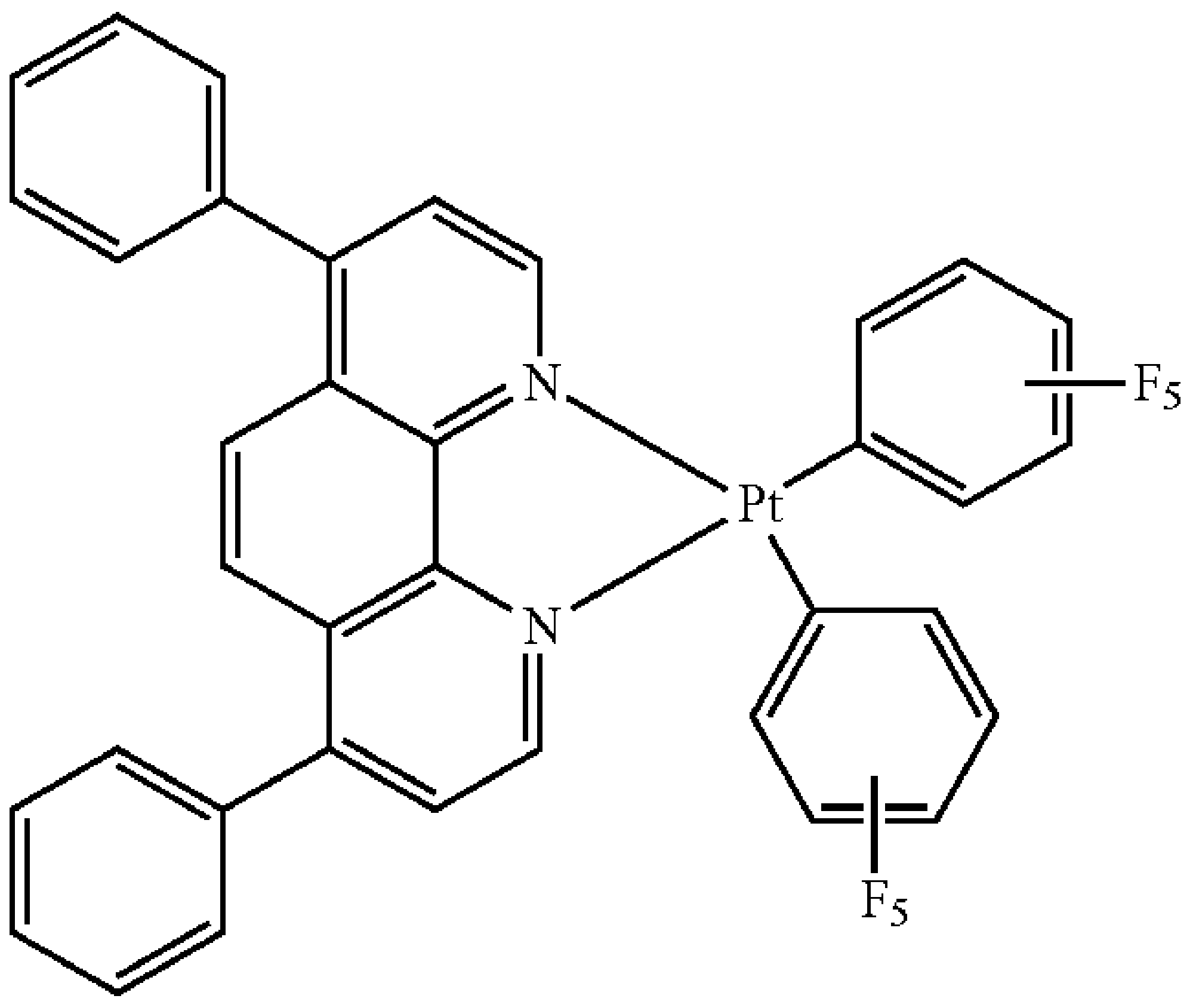
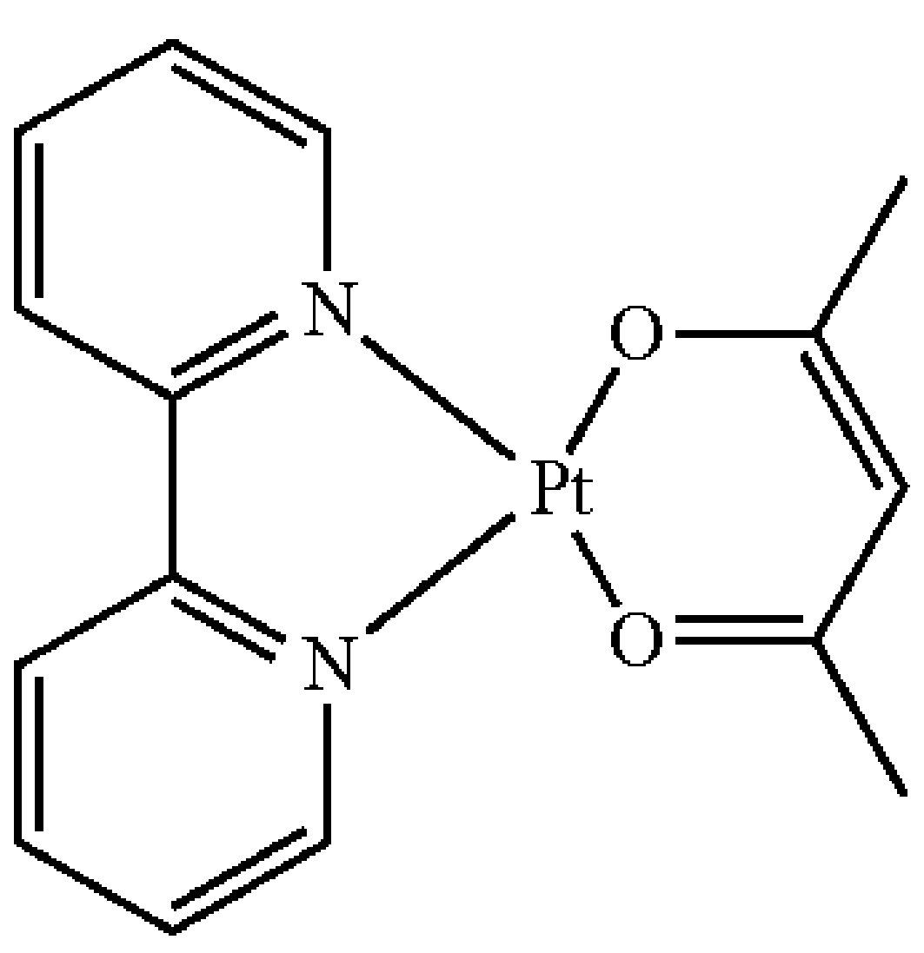
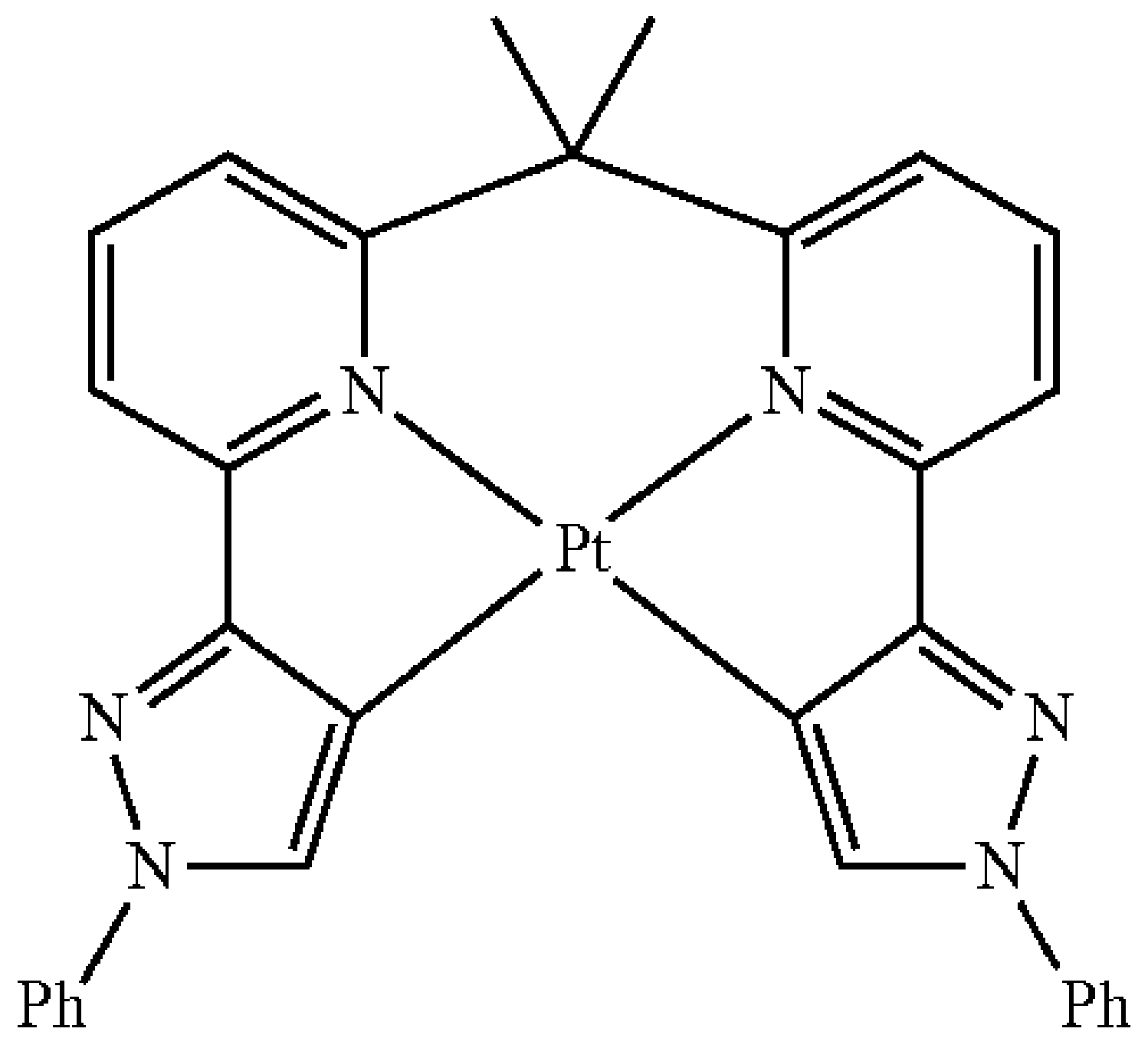
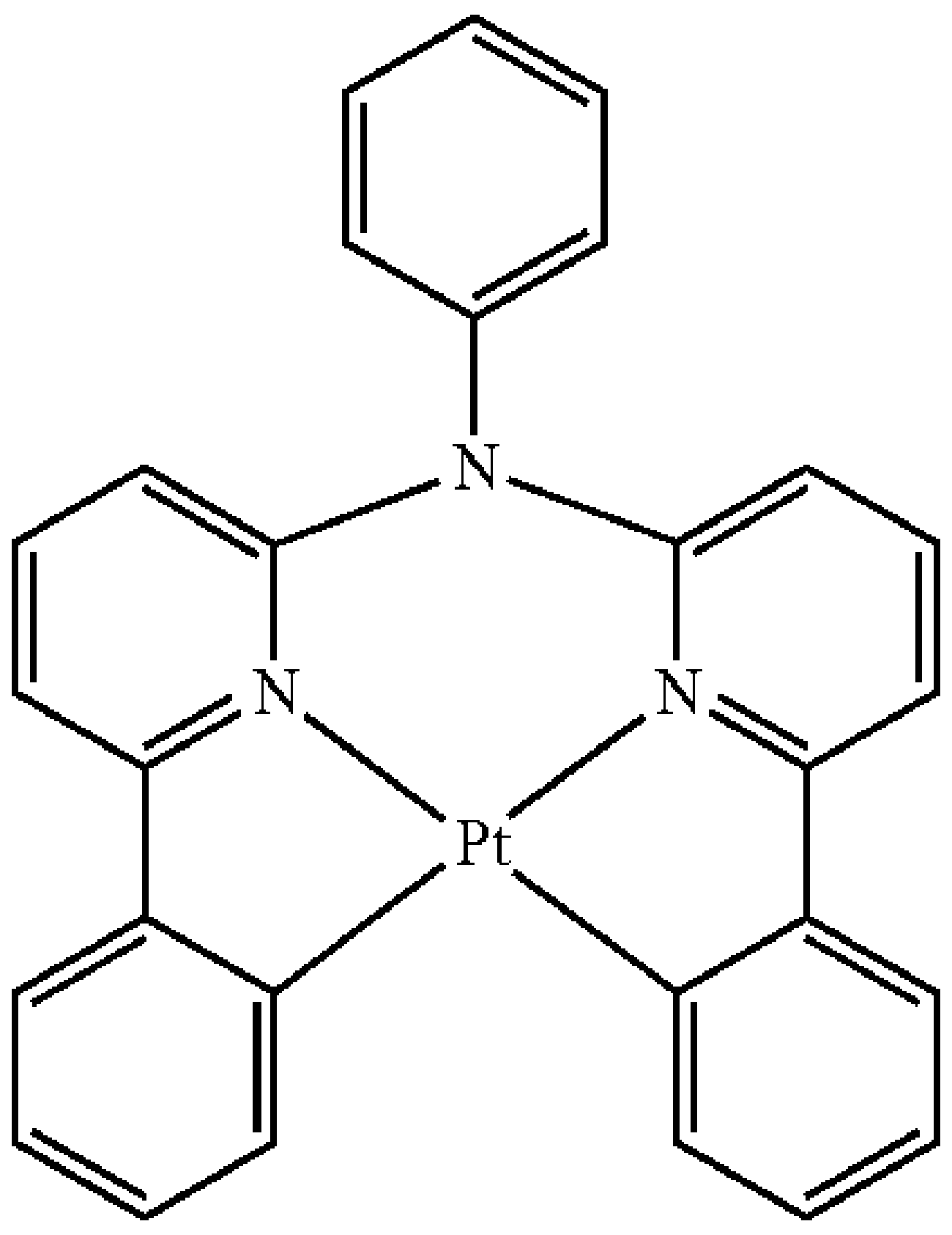
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		Appl. Phys. Lett. 86, 153505 (2005)
		Chem. Lett. 34, 592 (2005)
		WO2002015645
		US20060263635
		US20060182992 US20070103060

TABLE 4-continued

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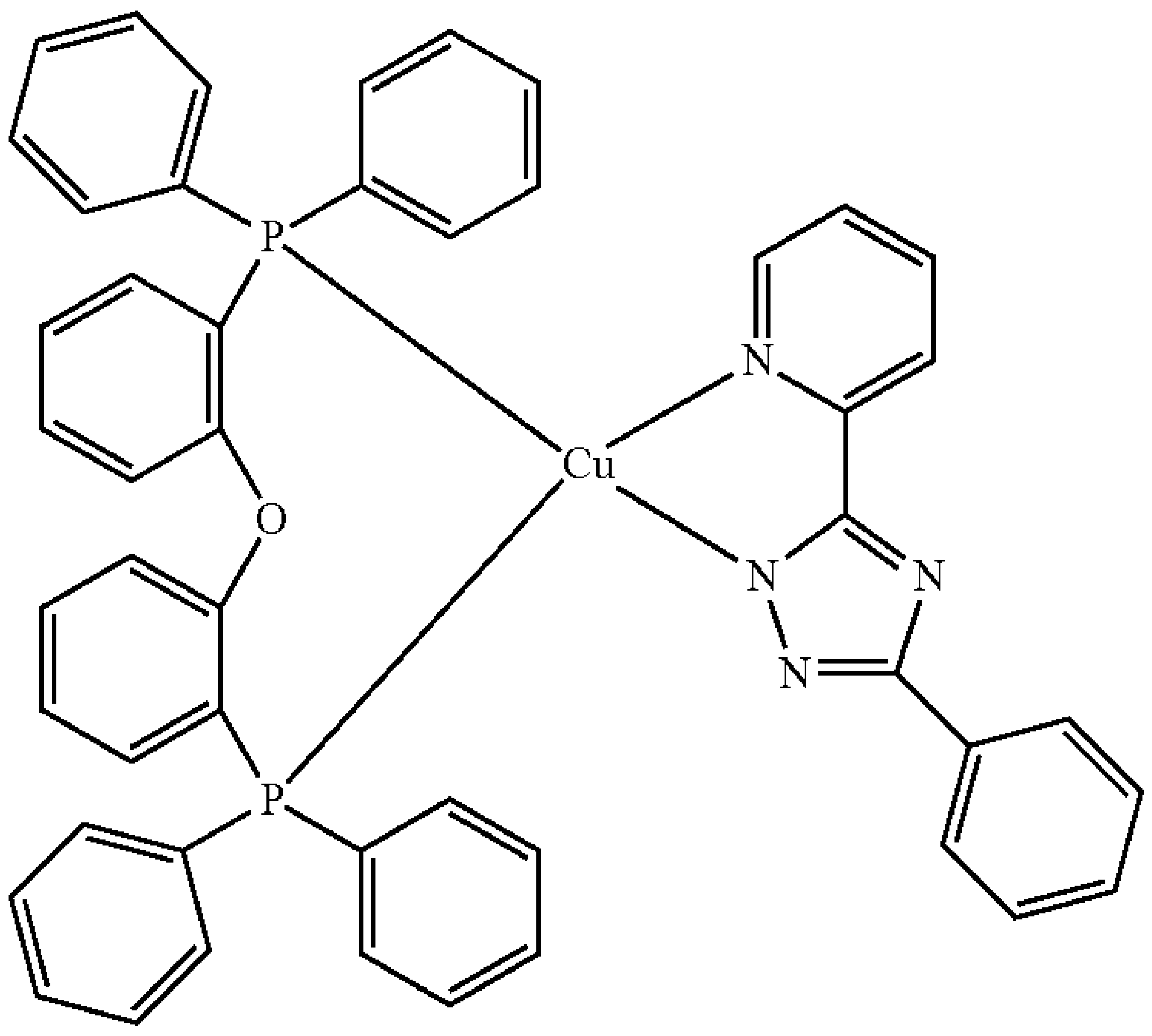
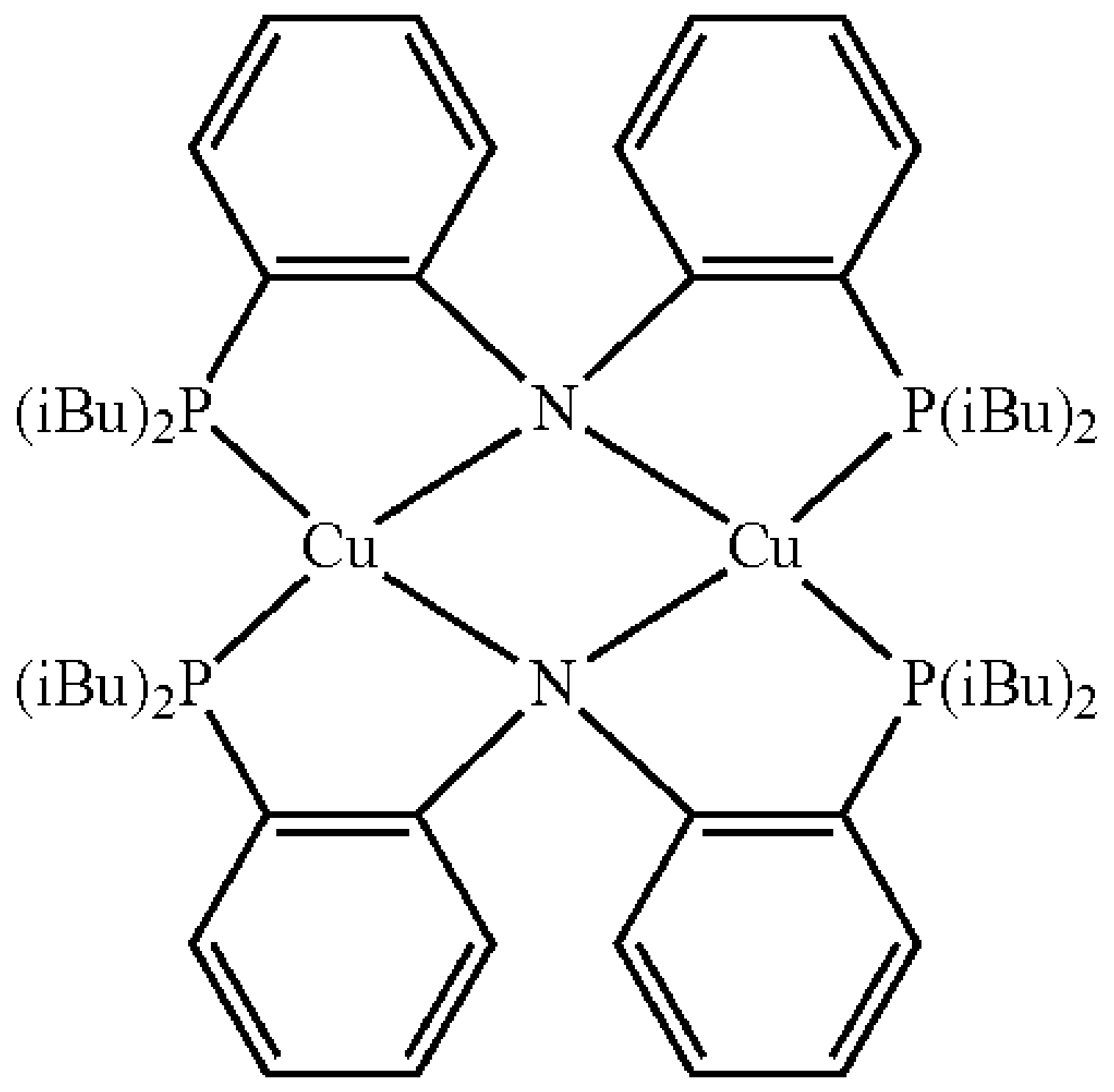
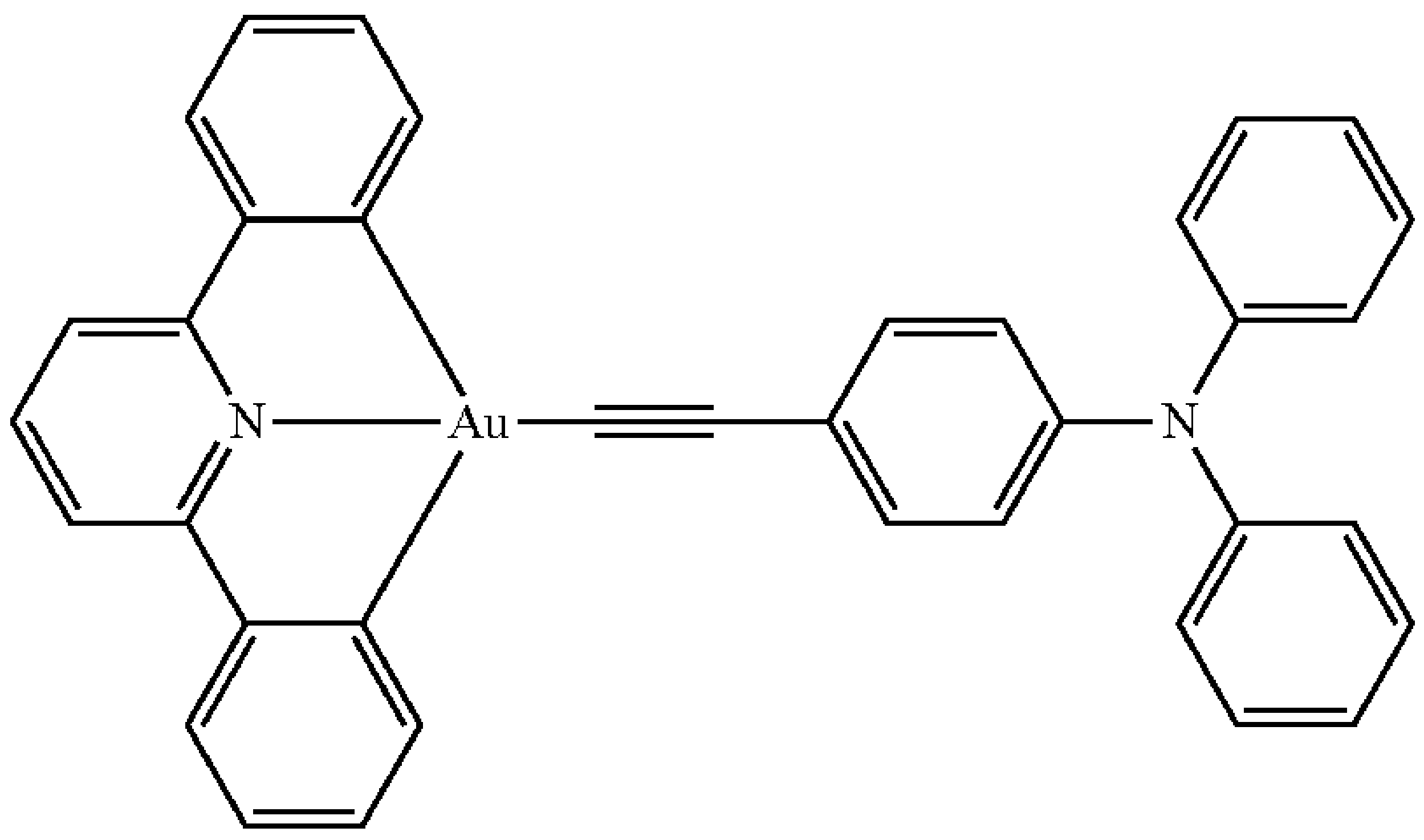
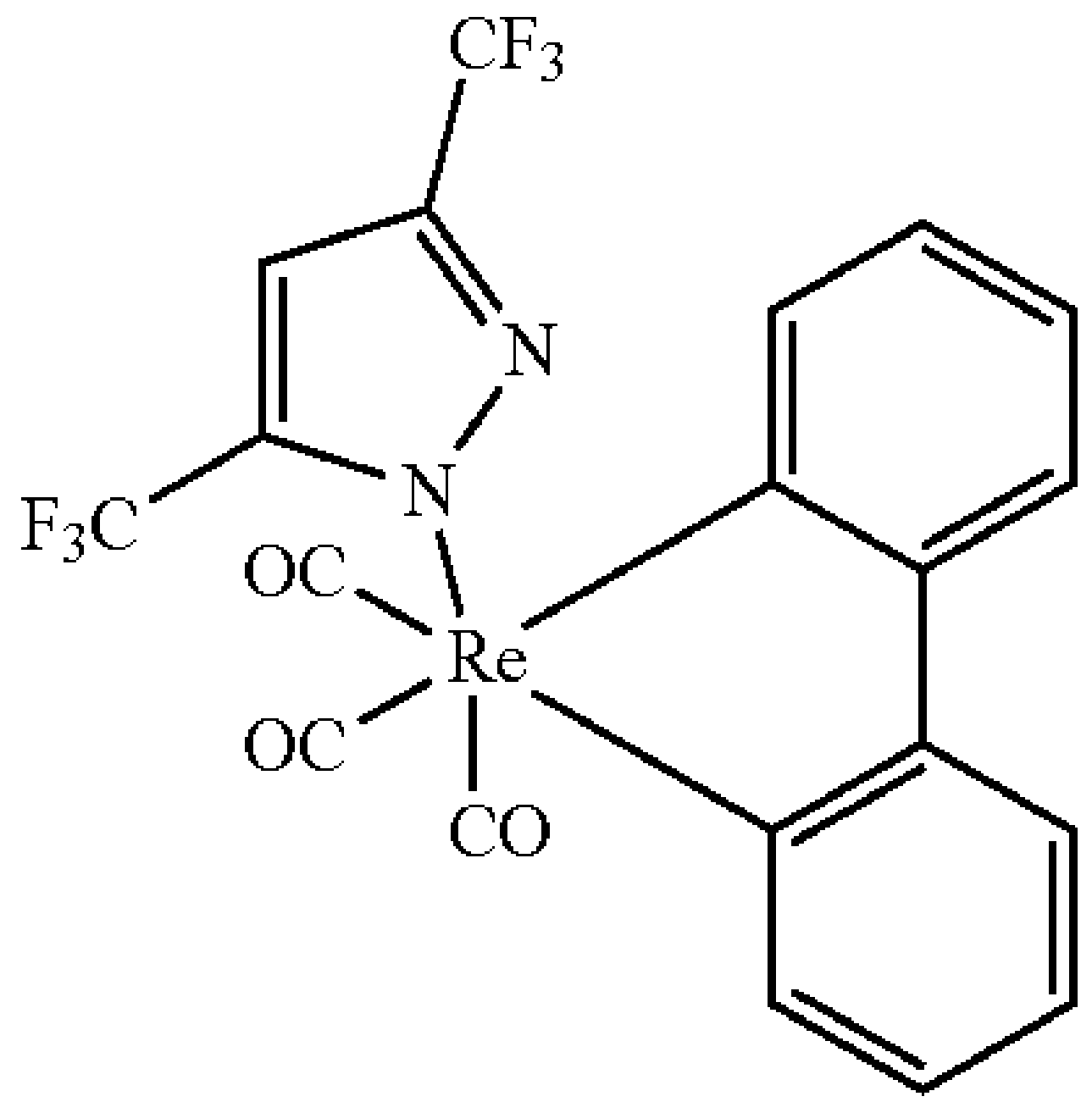
Cu complexes		WO2009000673
		US20070111026
Gold complexes		Chem. Commun. 2906 (2005)
Rhenium(III) complexes		Inorg. Chem. 42, 1248 (2003)

TABLE 4-continued

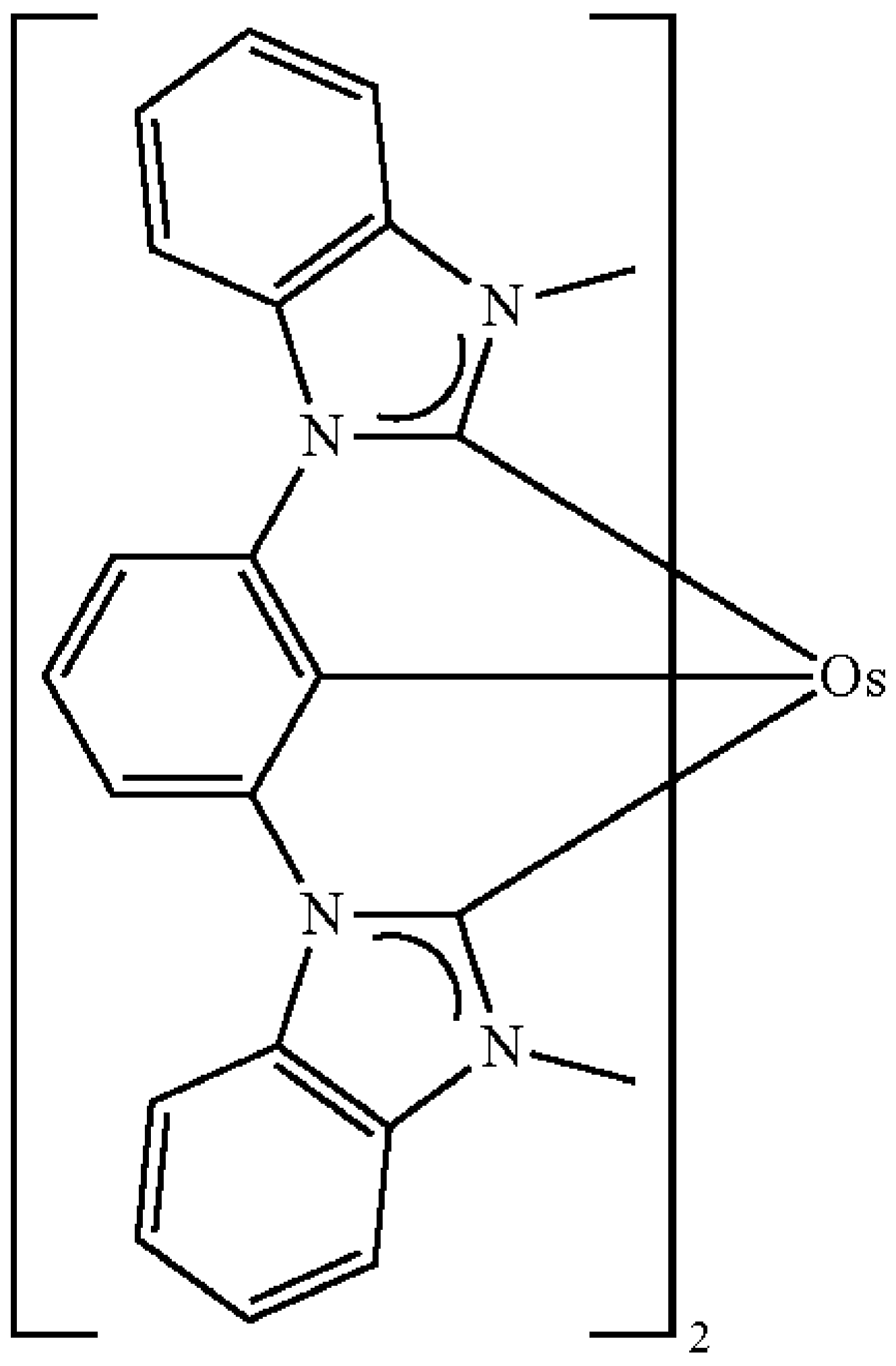
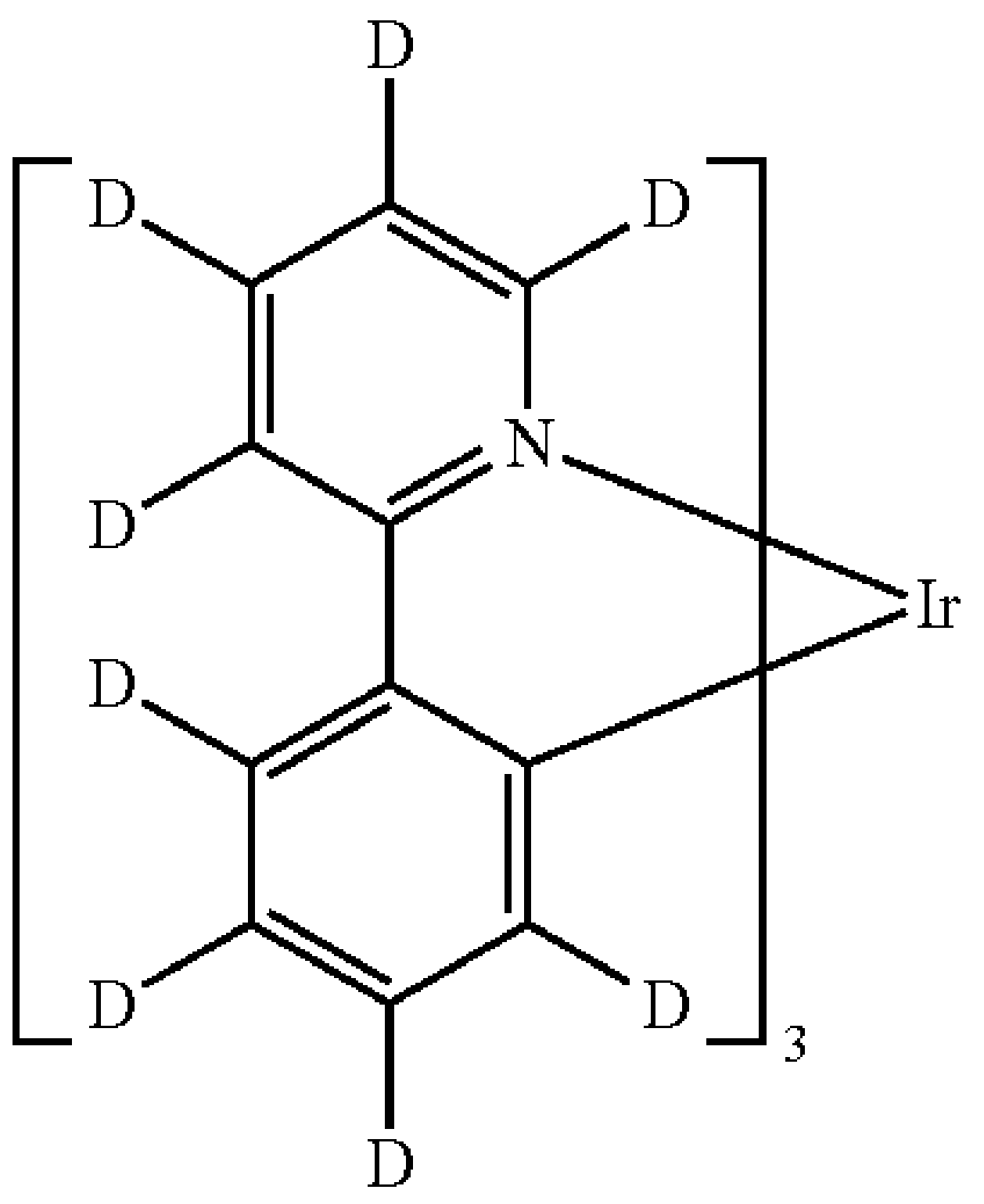
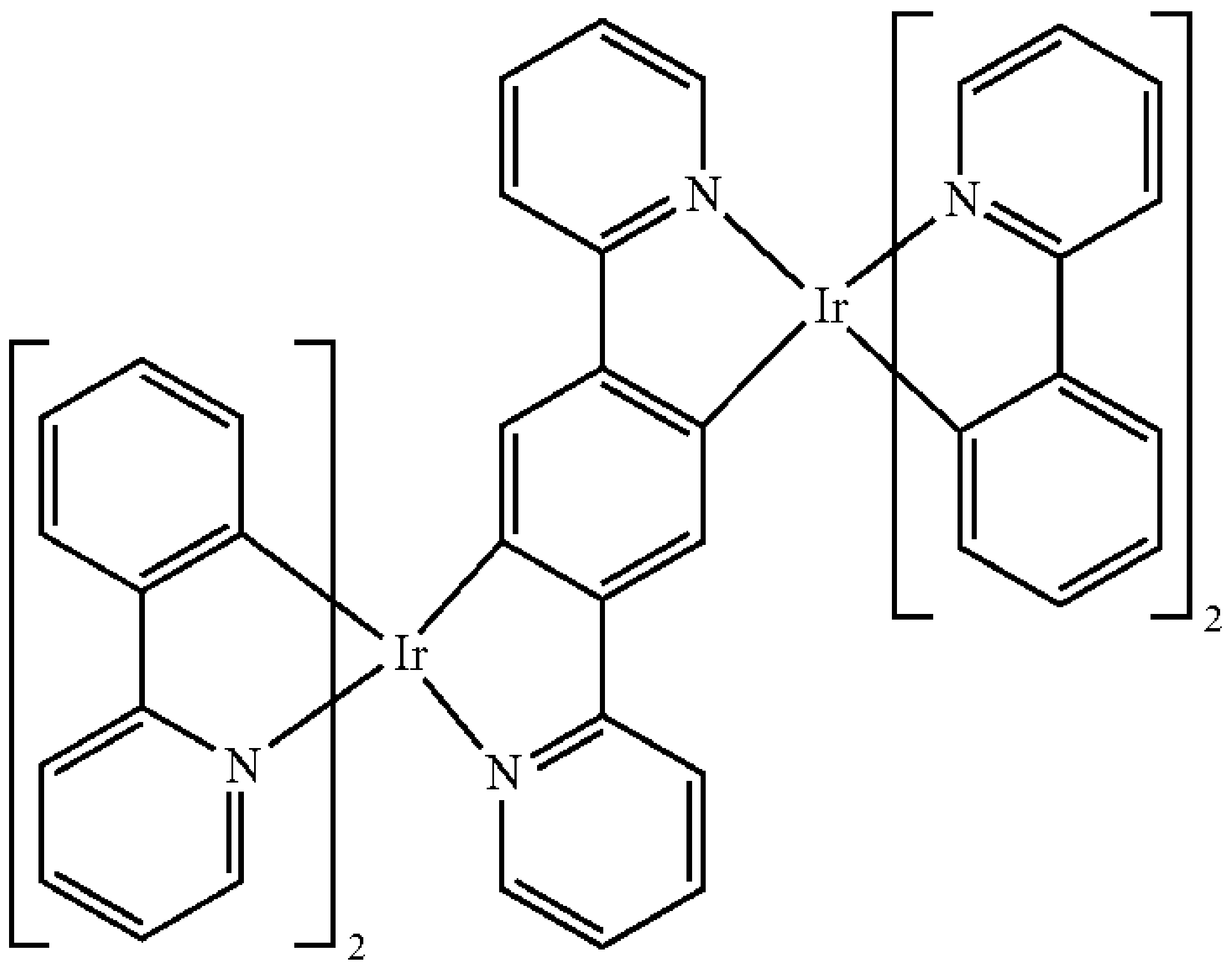
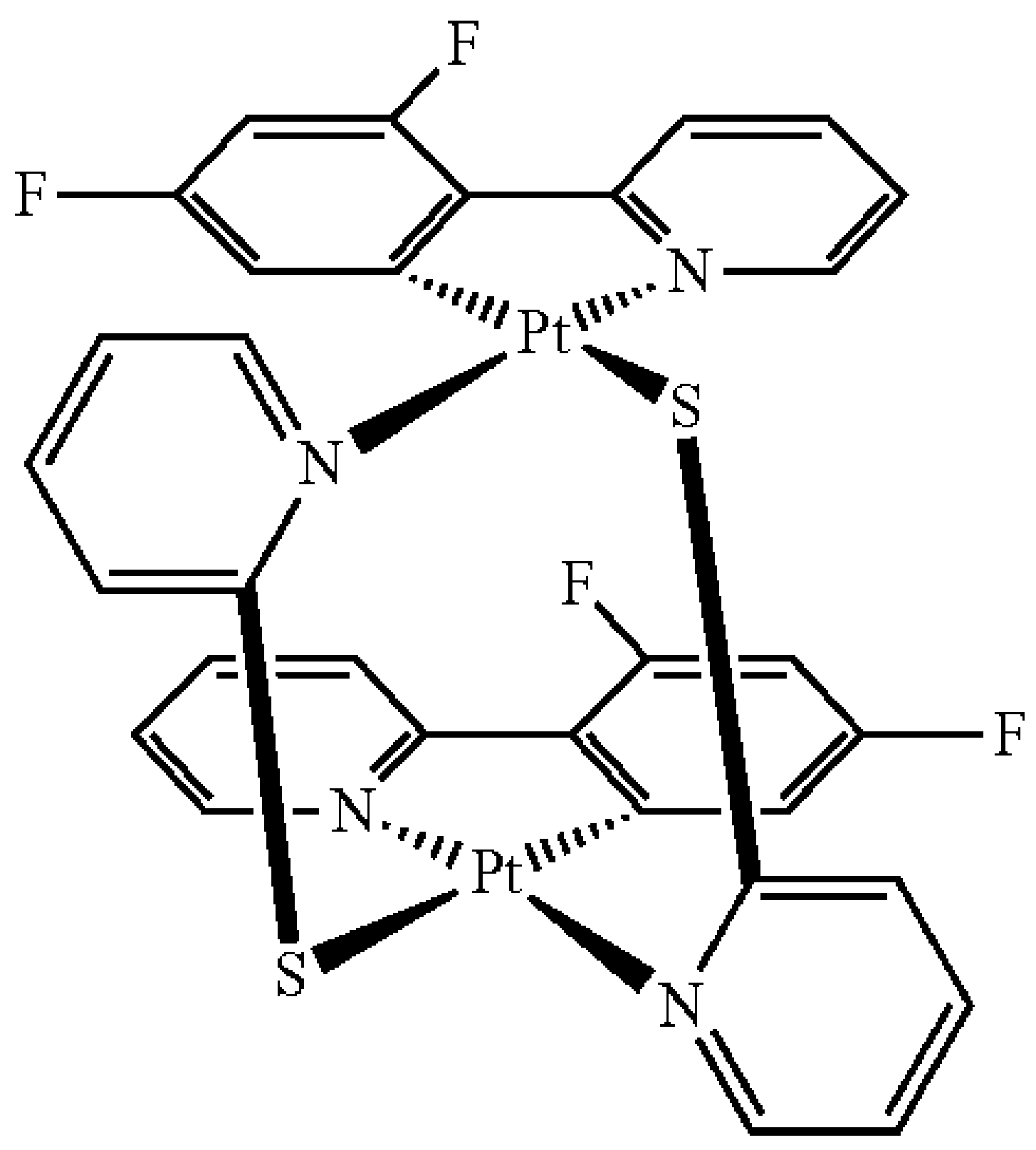
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Osmium(II) complexes		U.S. Pat. No. 7,279,704
Deuterated organometallic complexes		US20030138657
Organometallic complexes with two or more metal centers		US20030152802
		U.S. Pat. No. 7,090,928

TABLE 4-continued

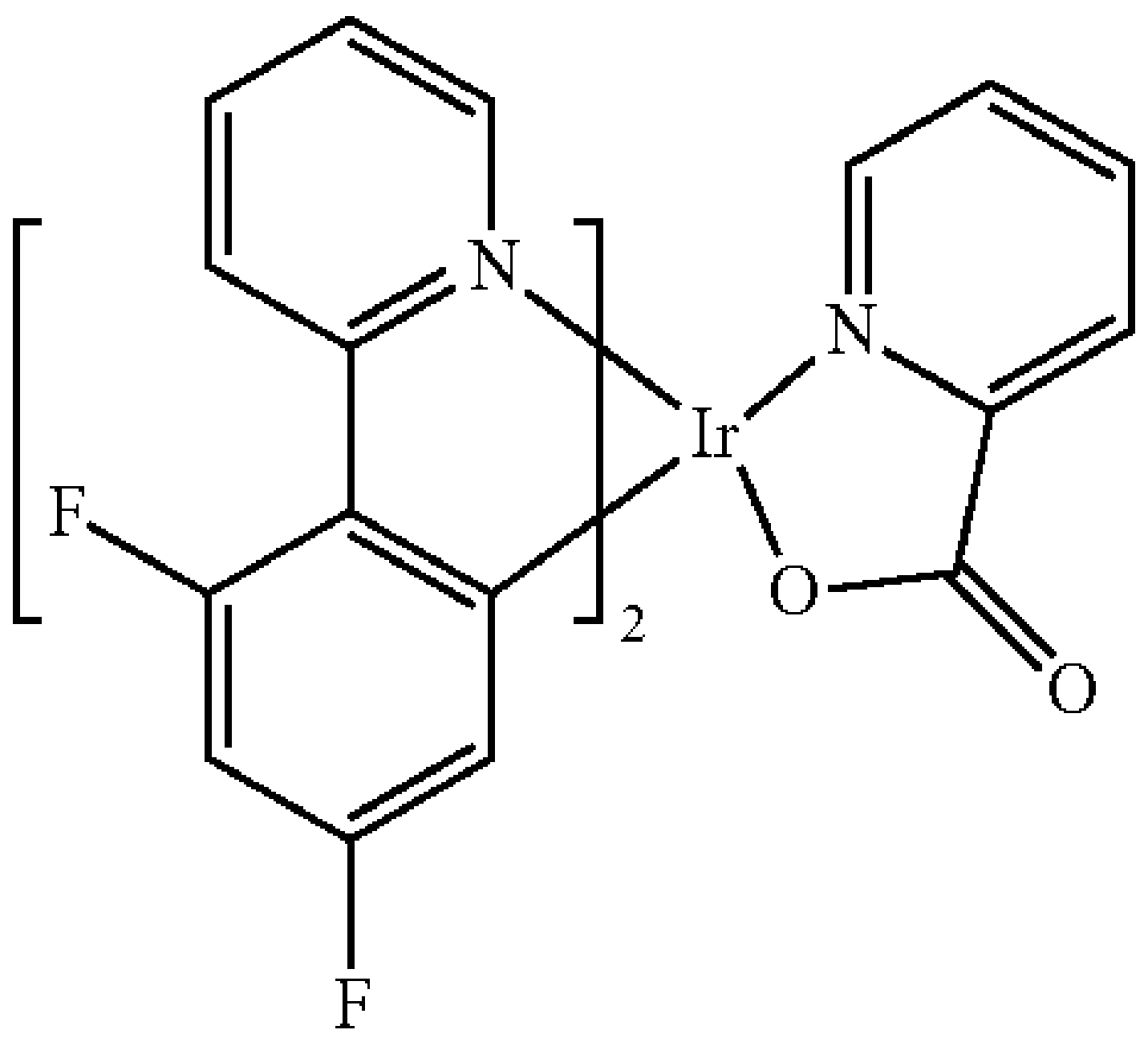
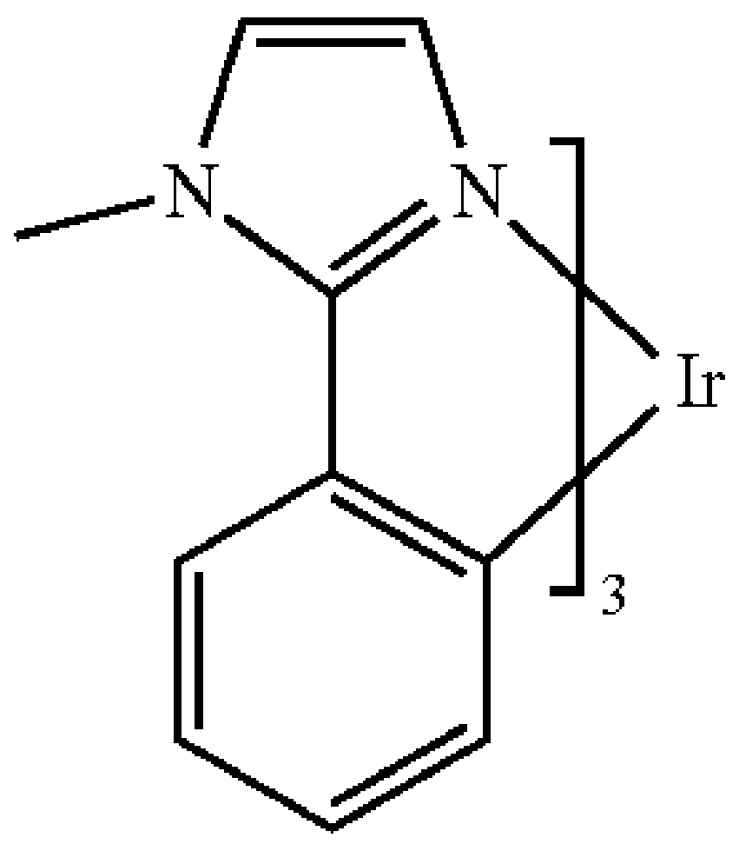
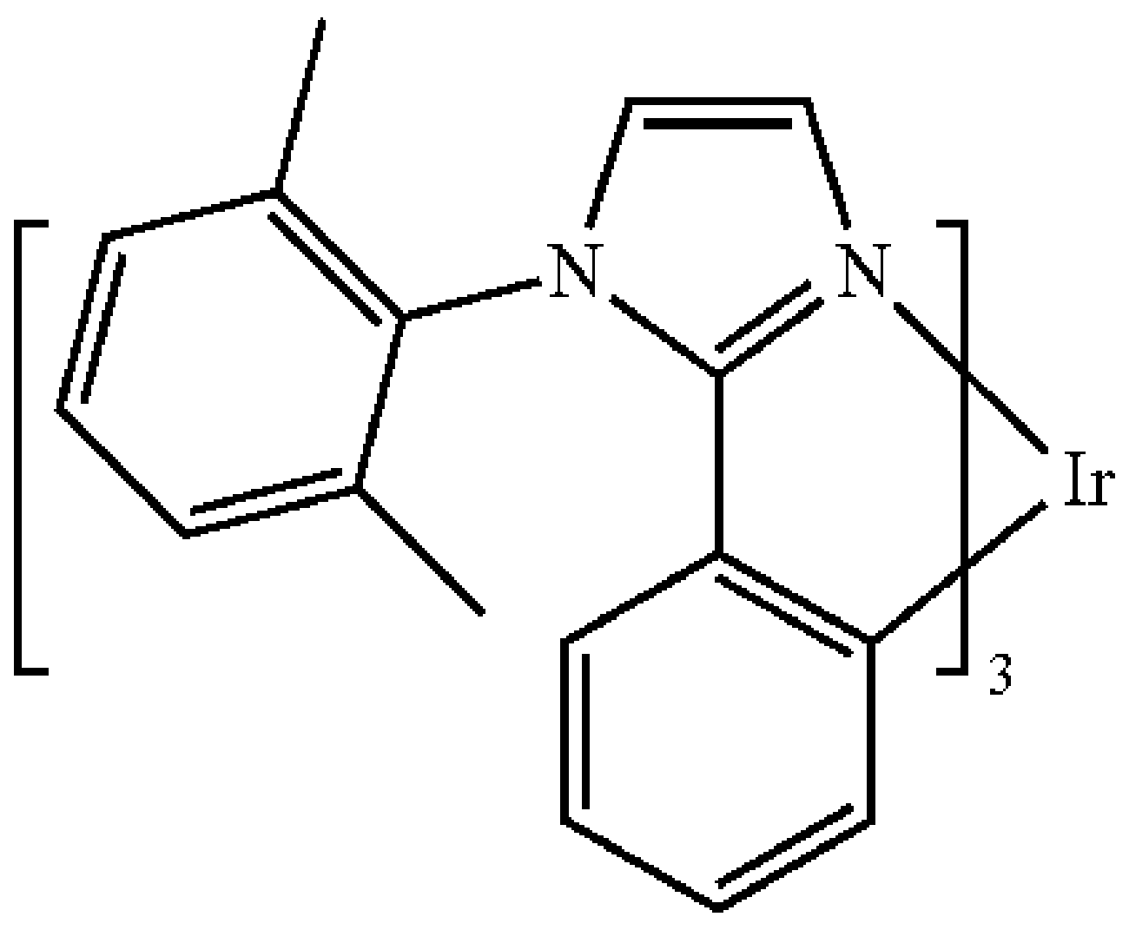
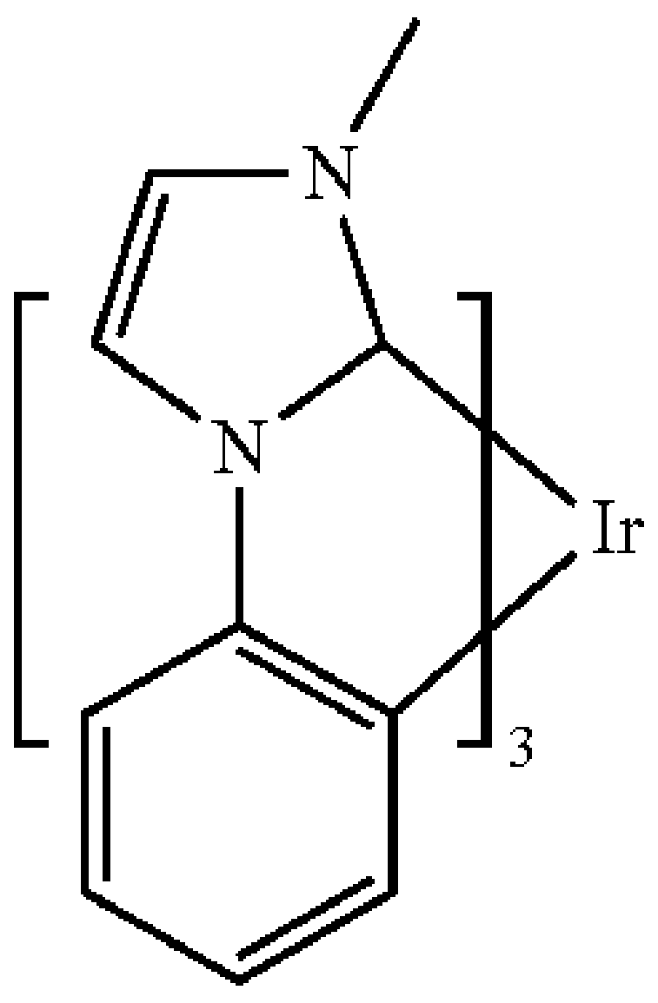
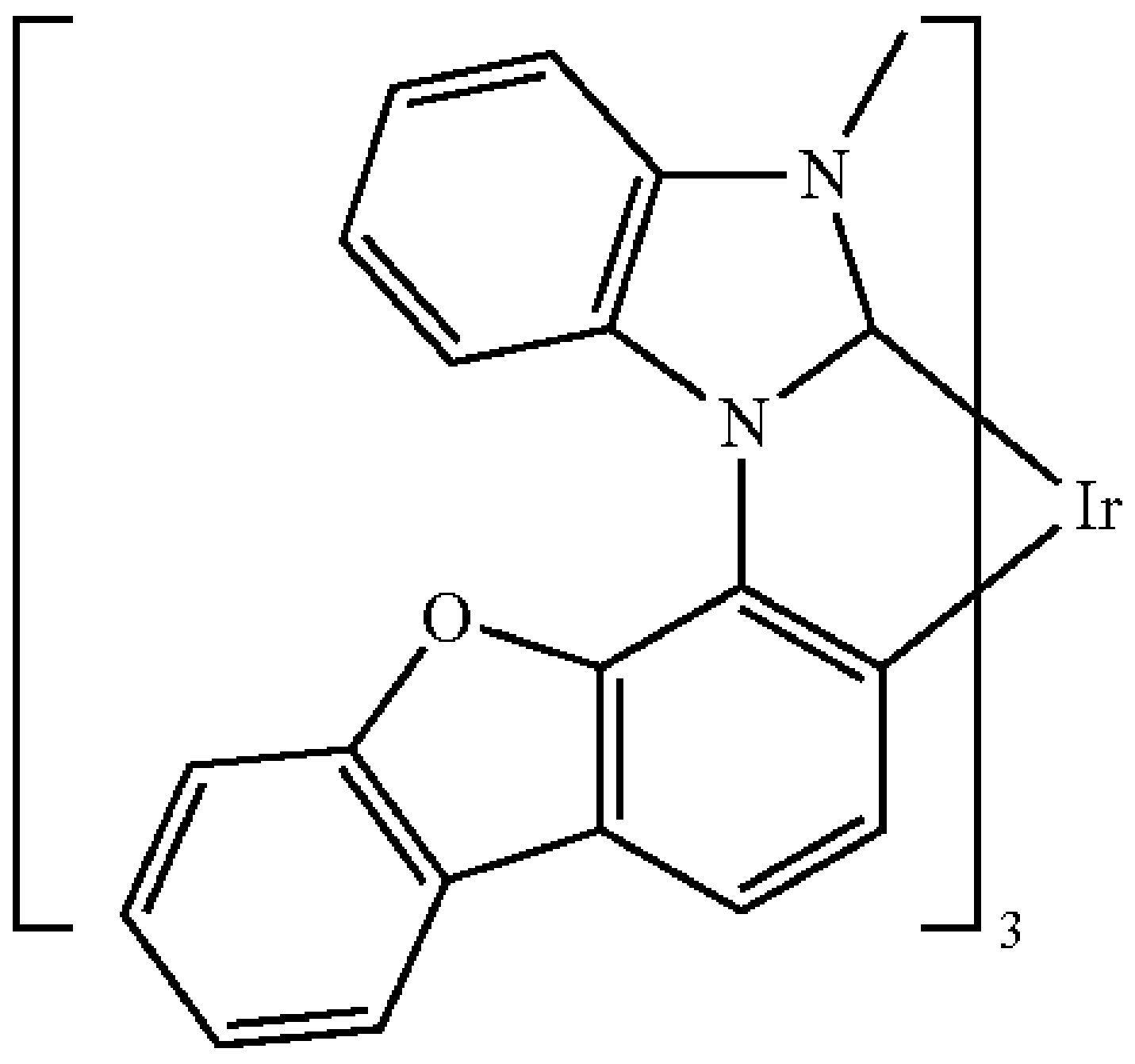
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
	Blue dopants	
Iridium(III) organometallic complexes		WO2002002714
		WO2006009024
		US20060251923 US20110057559 US20110204333
		U.S. Pat. No. 7,393,599, WO2006056418, US20050260441, WO2005019373
		U.S. Pat. No. 7,534,505

TABLE 4-continued

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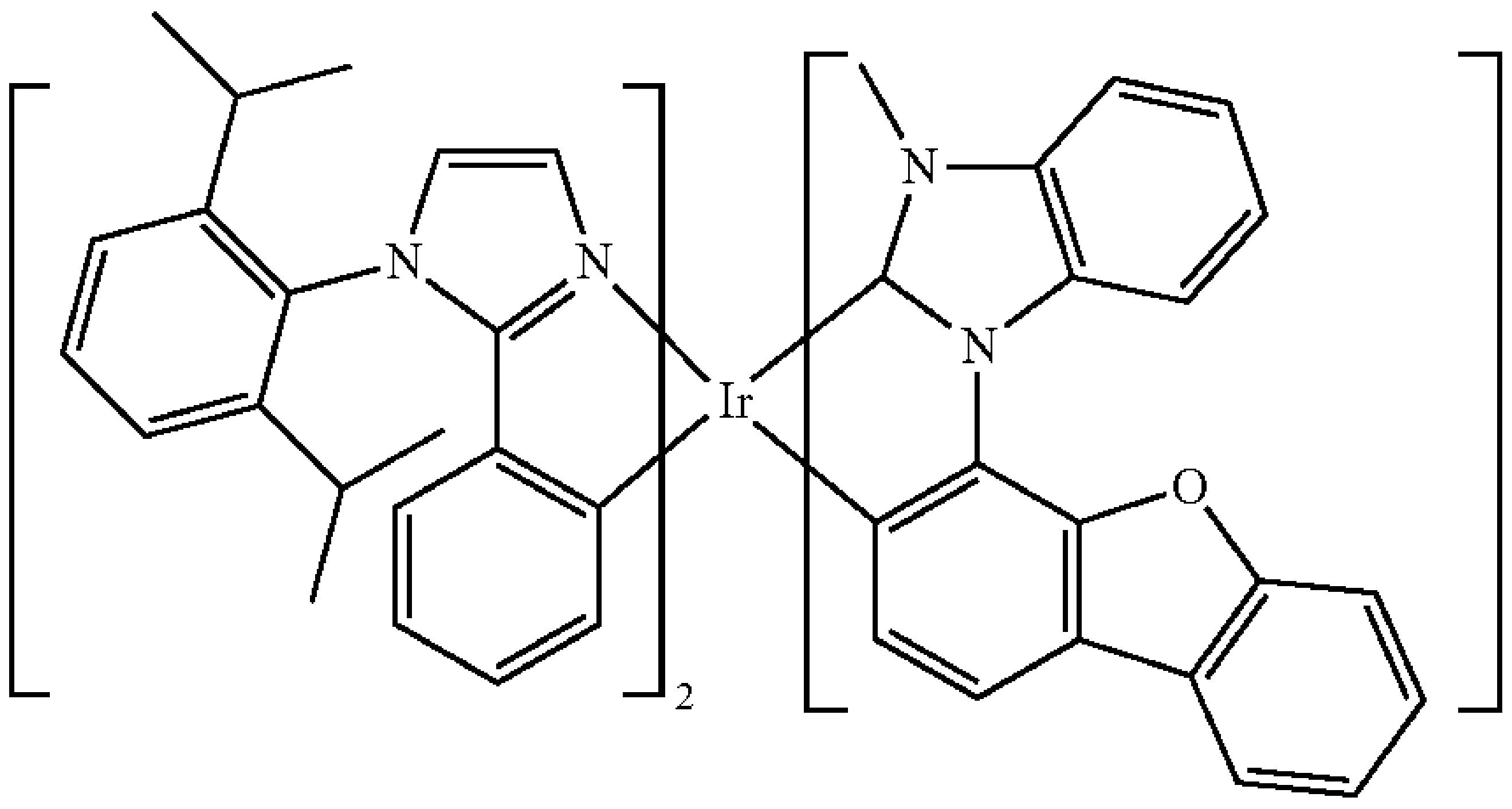
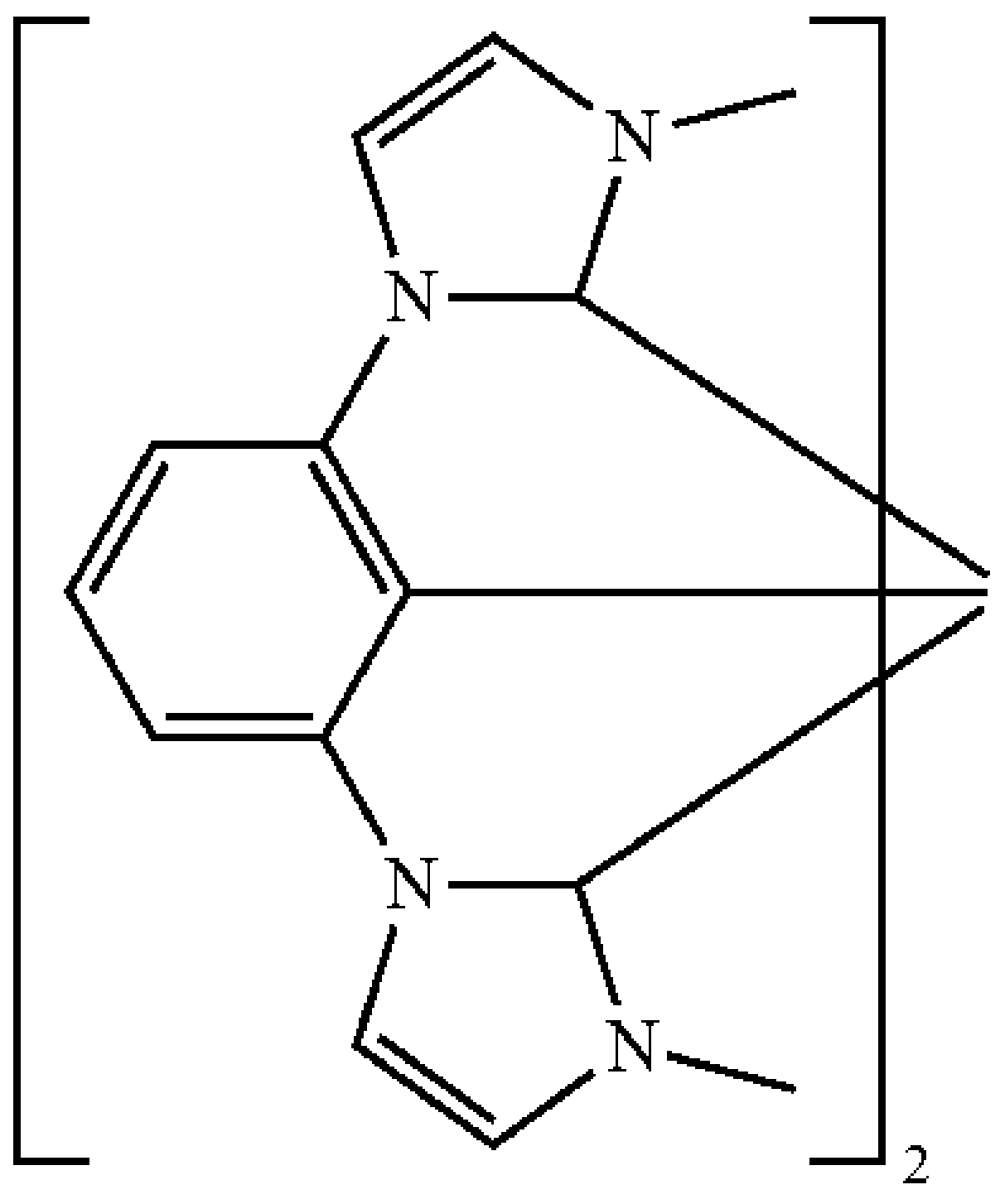
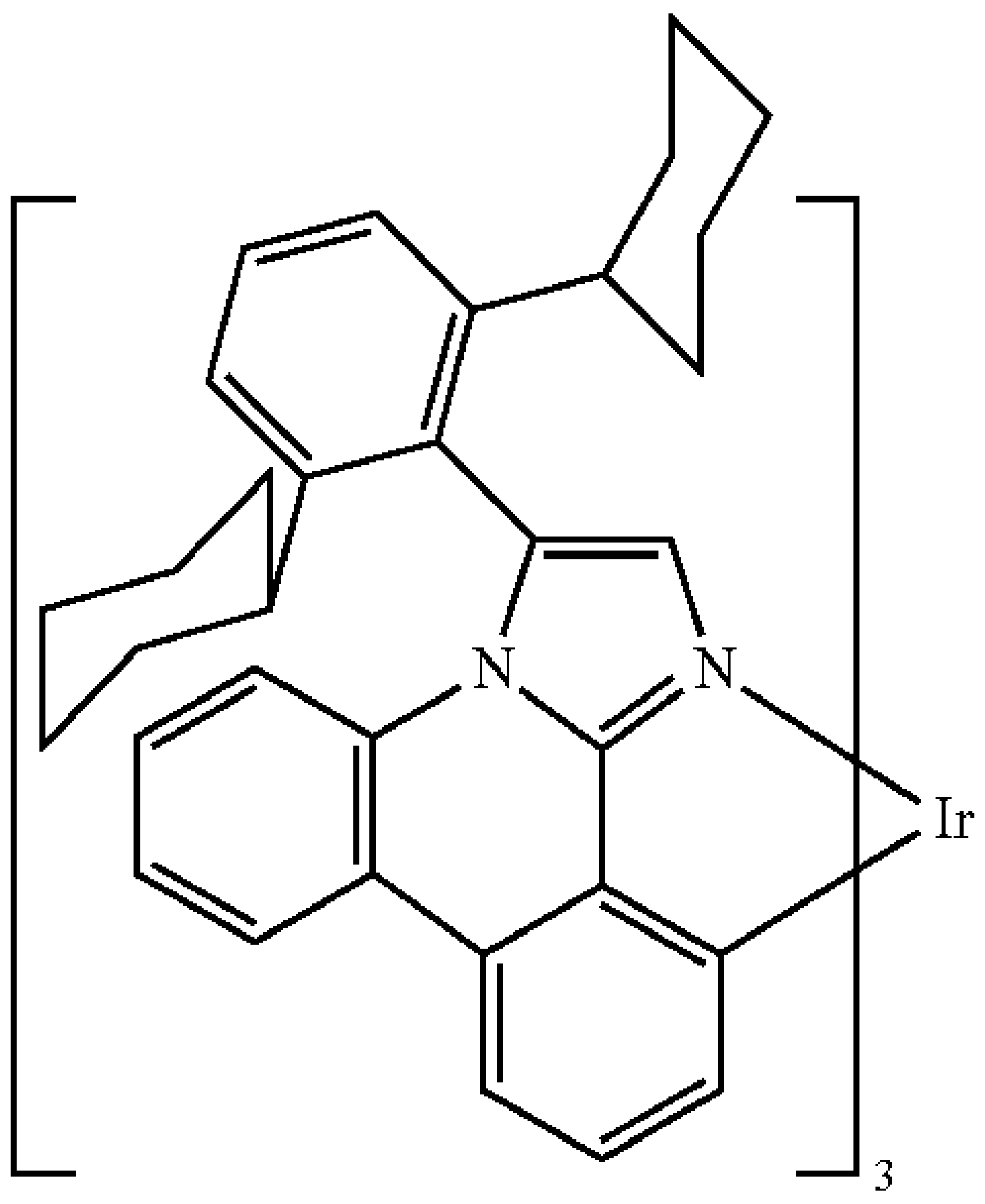
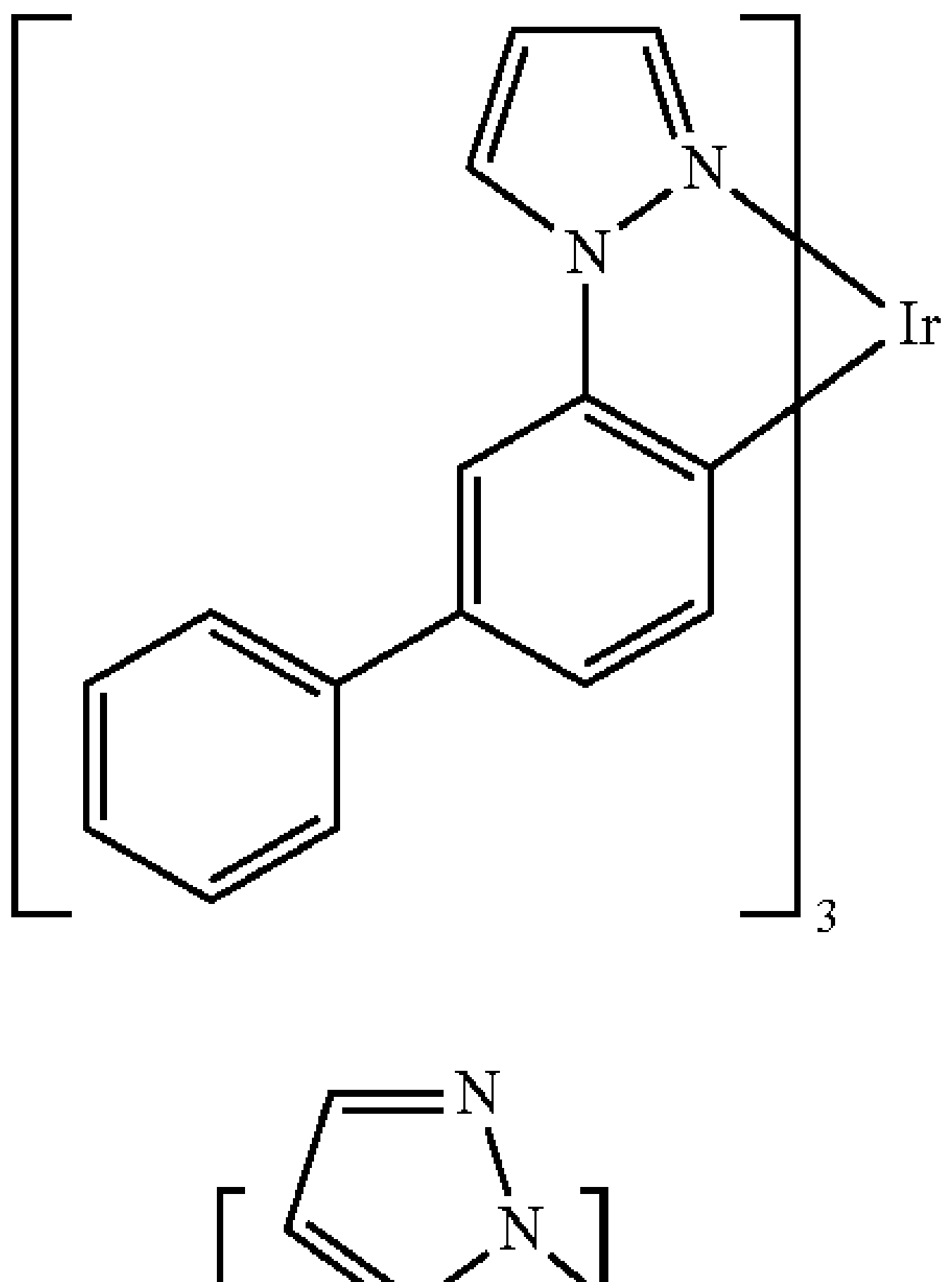
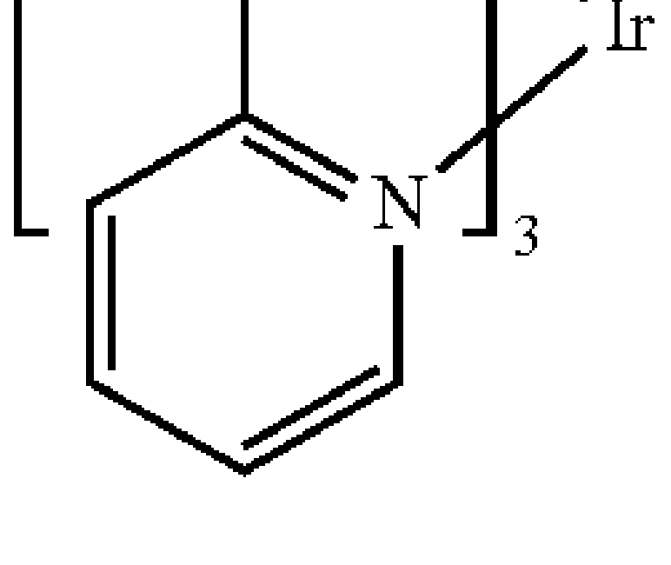
		WO2011051404
		U.S. Pat. No. 7,445,855
		US20070190359, US20080297033 US20100148663
		U.S. Pat. No. 7,338,722
		US20020134984

TABLE 4-continued

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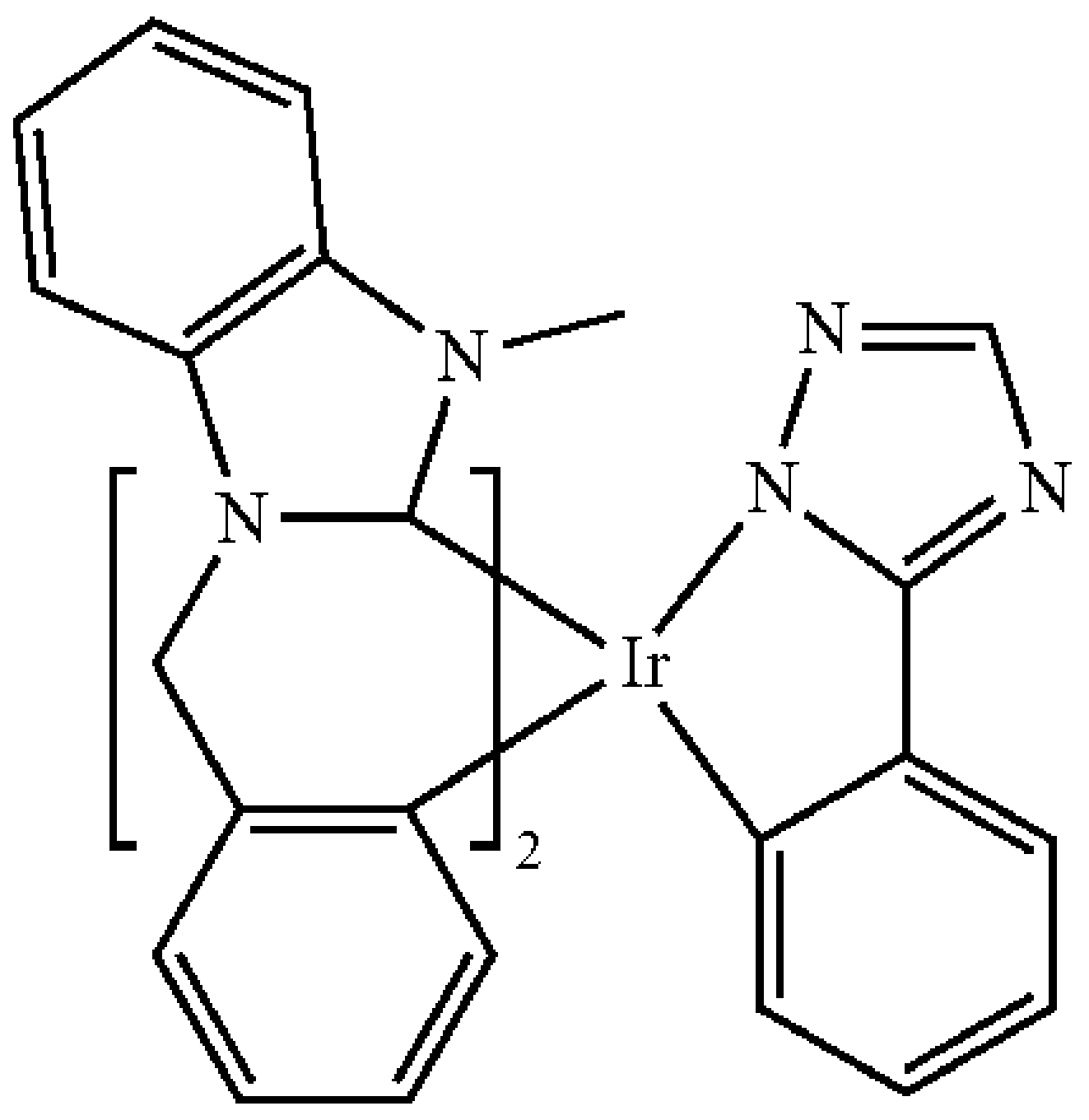
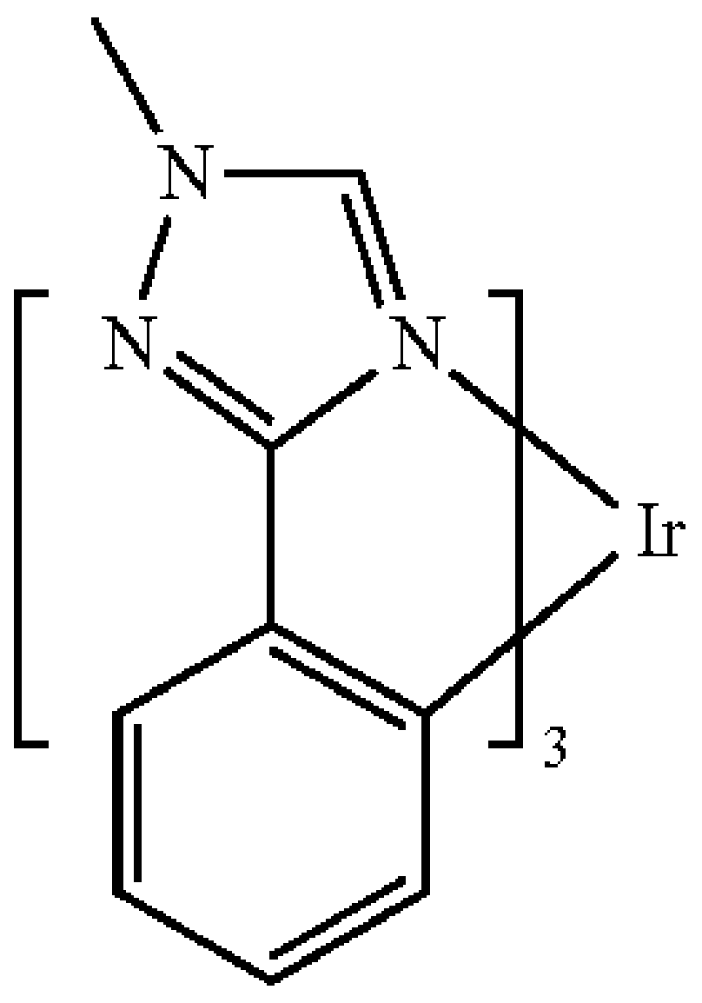
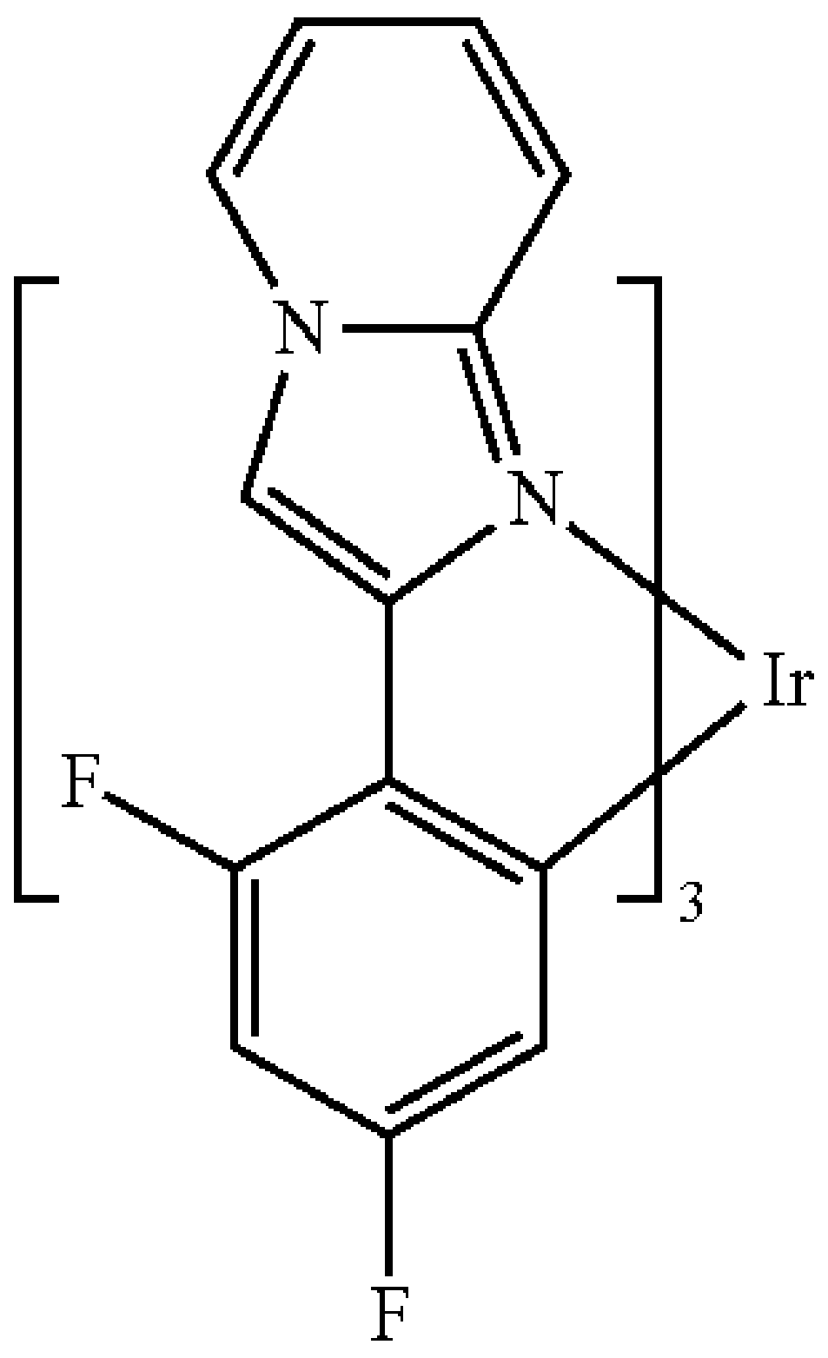
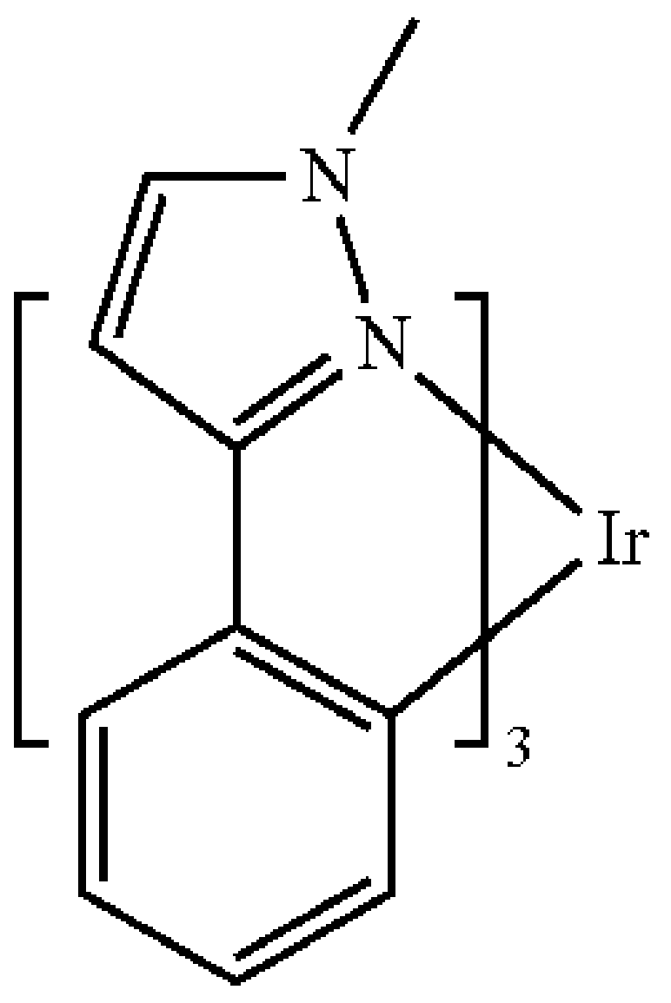
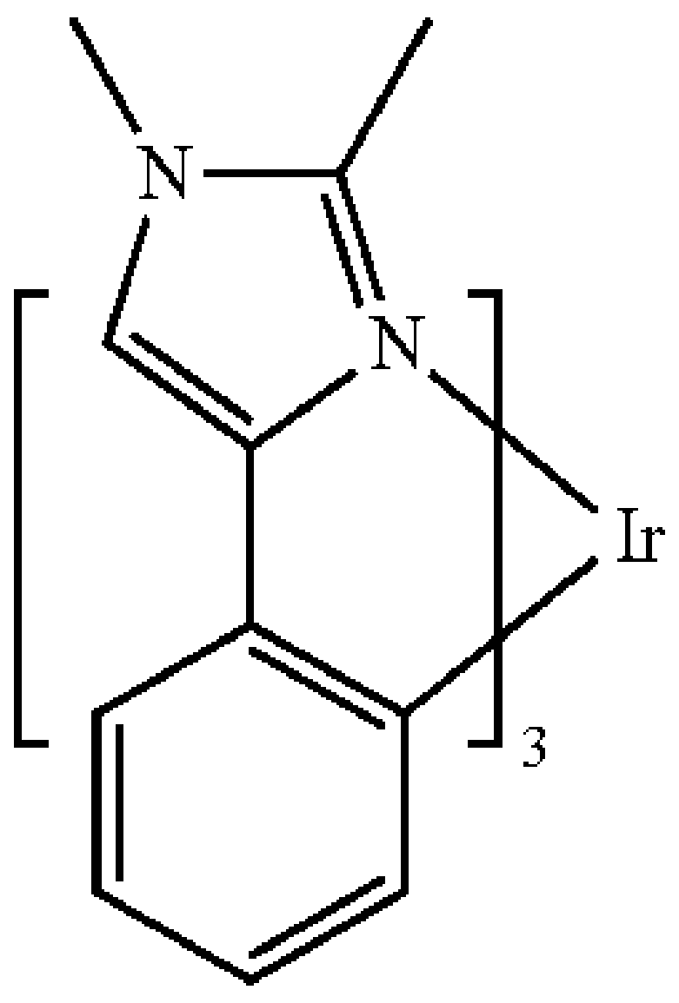
		Angew. Chem. Int. Ed. 47, 1 (2008)
		Chem. Mater. 18, 5119 (2006)
		Inorg. Chem. 46, 4308 (2007)
		WO2005123873
		WO2005123873

TABLE 4-continued

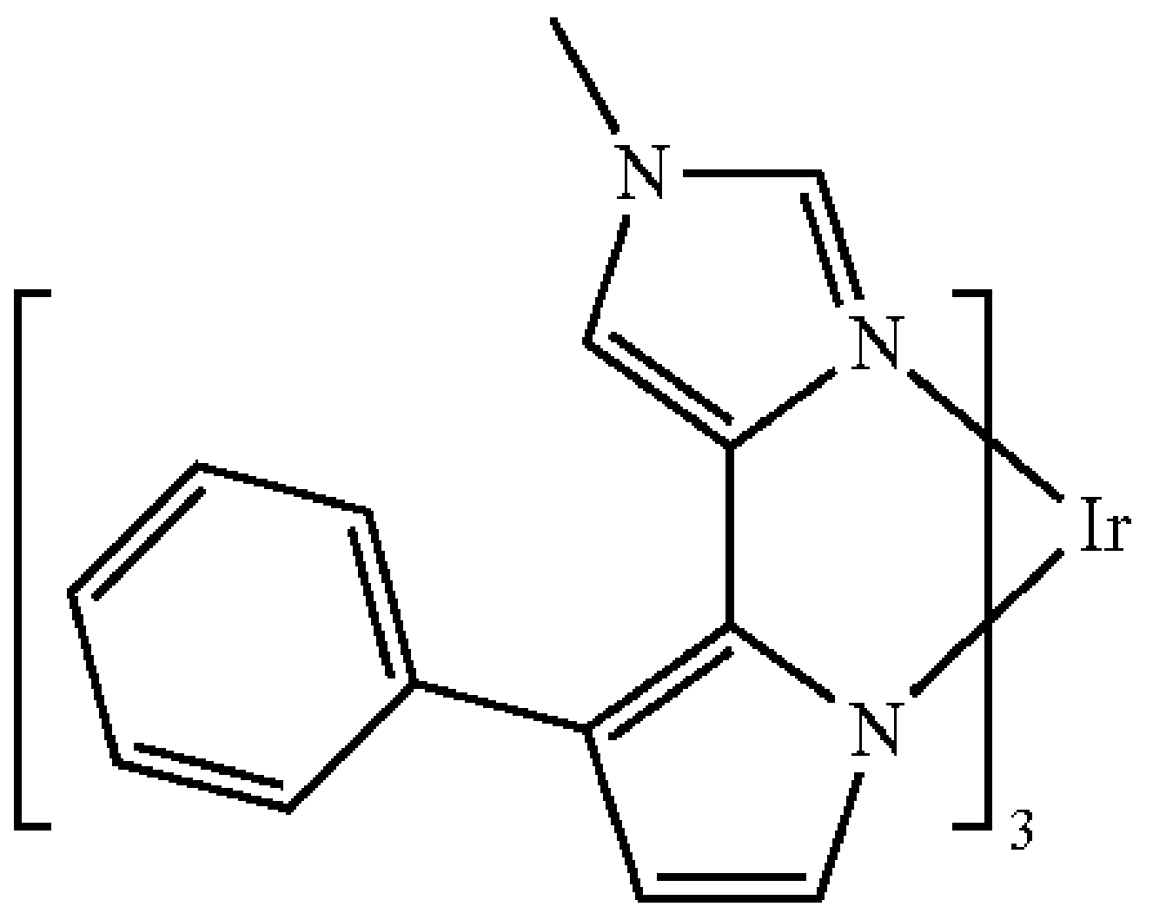
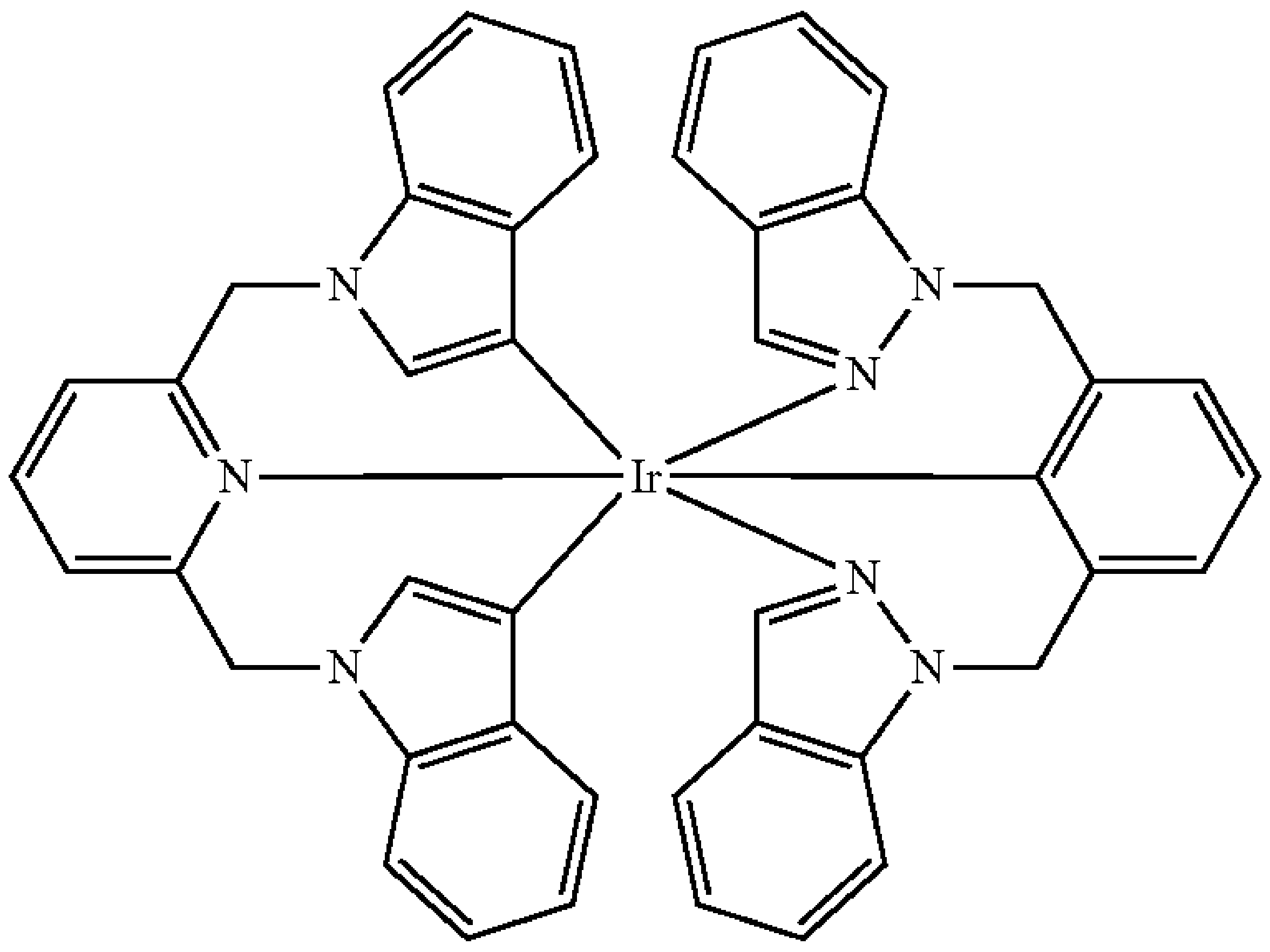
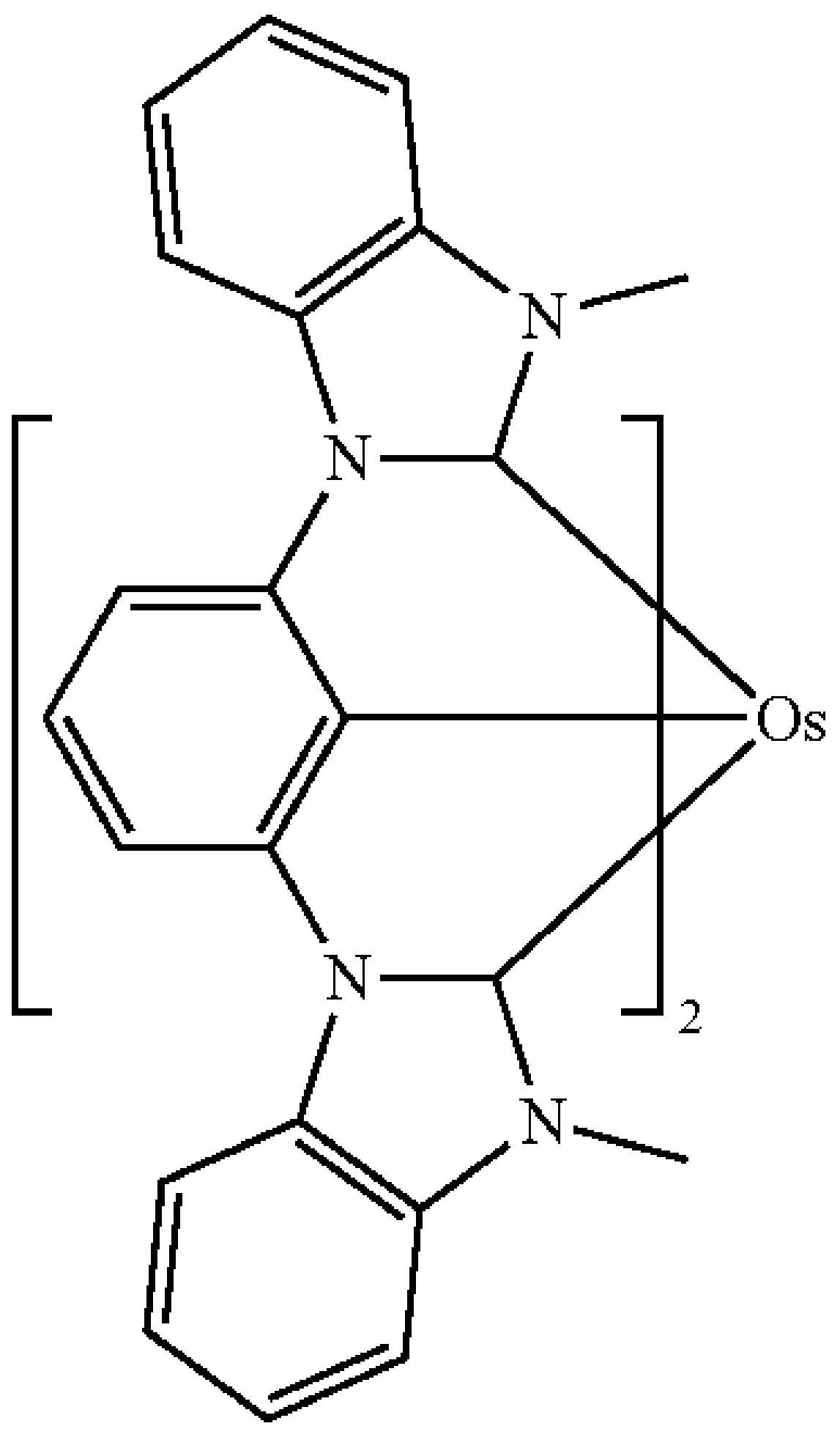
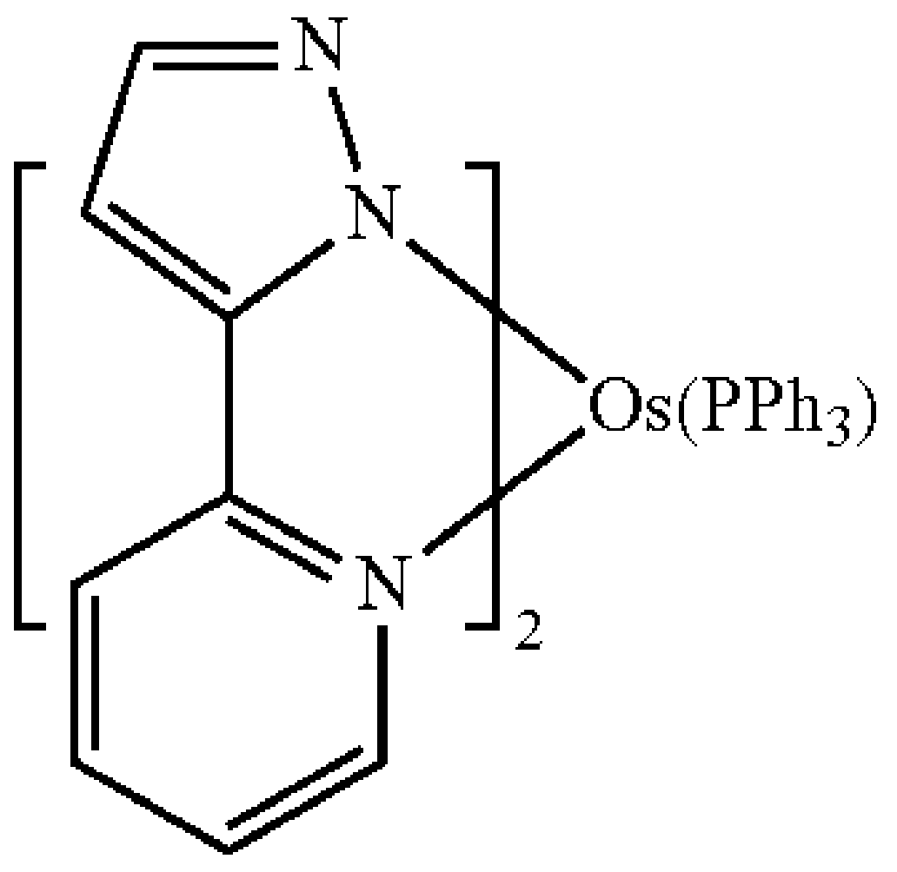
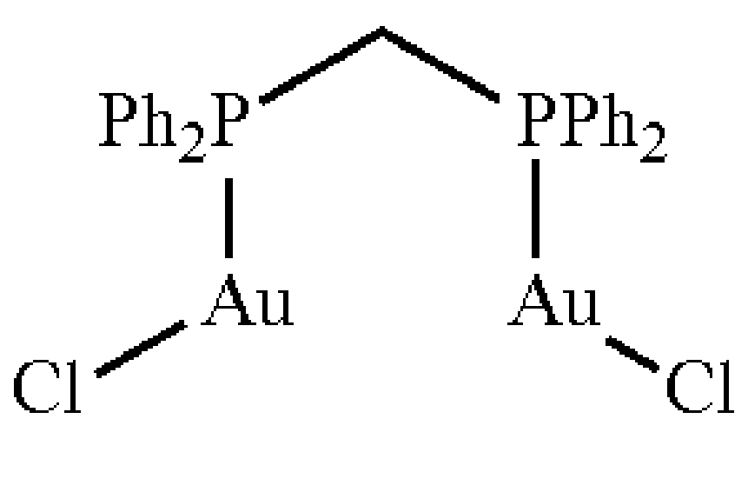
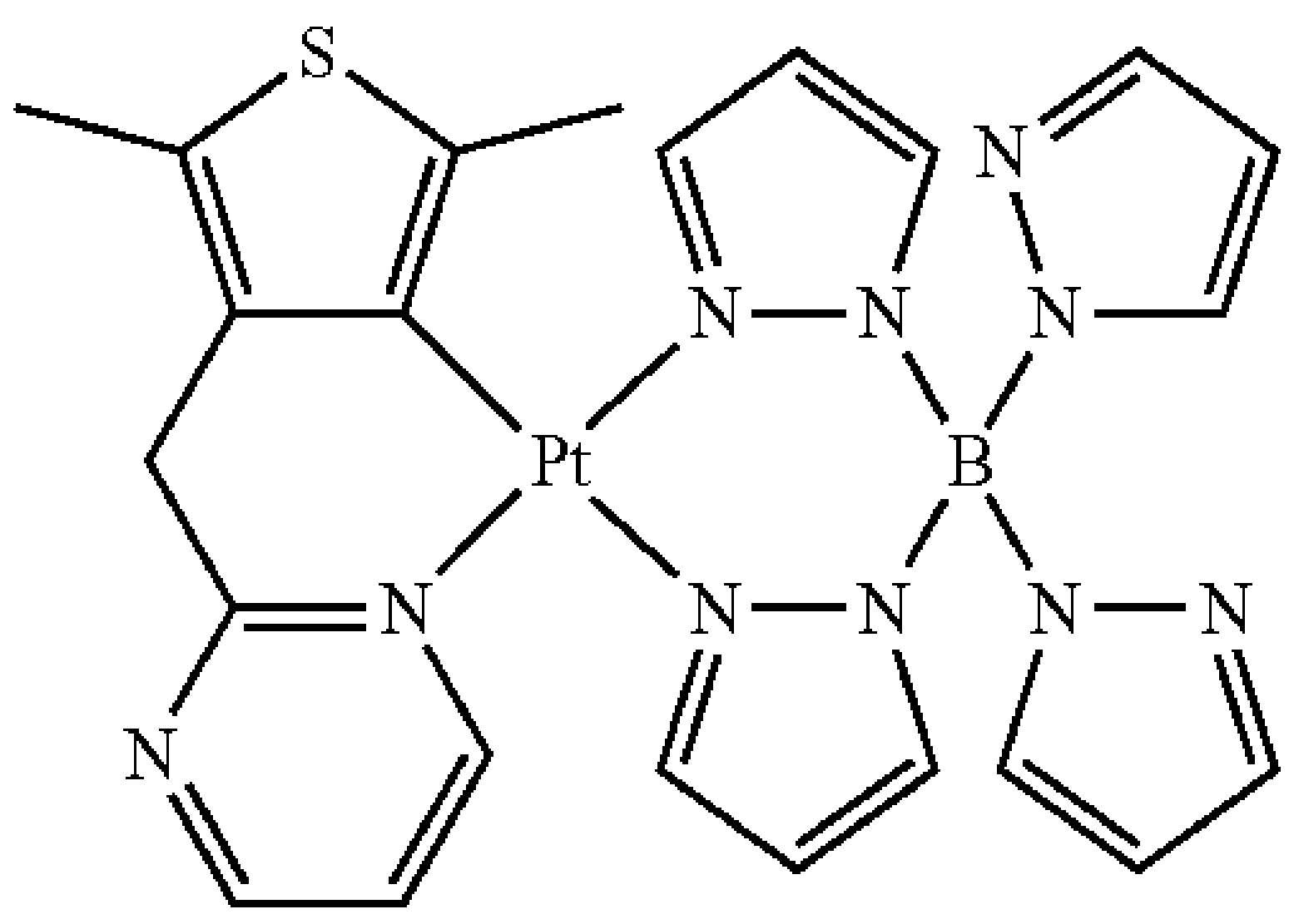
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
		WO2007004380
		WO2006082742
Osmium(II) complexes		U.S. Pat. No. 7,279,704
		Organometallics 23, 3745 (2004)
Gold complexes		Appl. Phys. Lett. 74, 1361 (1999)
Platinum(II) complexes		WO2006098120, WO2006103874

TABLE 4-continued

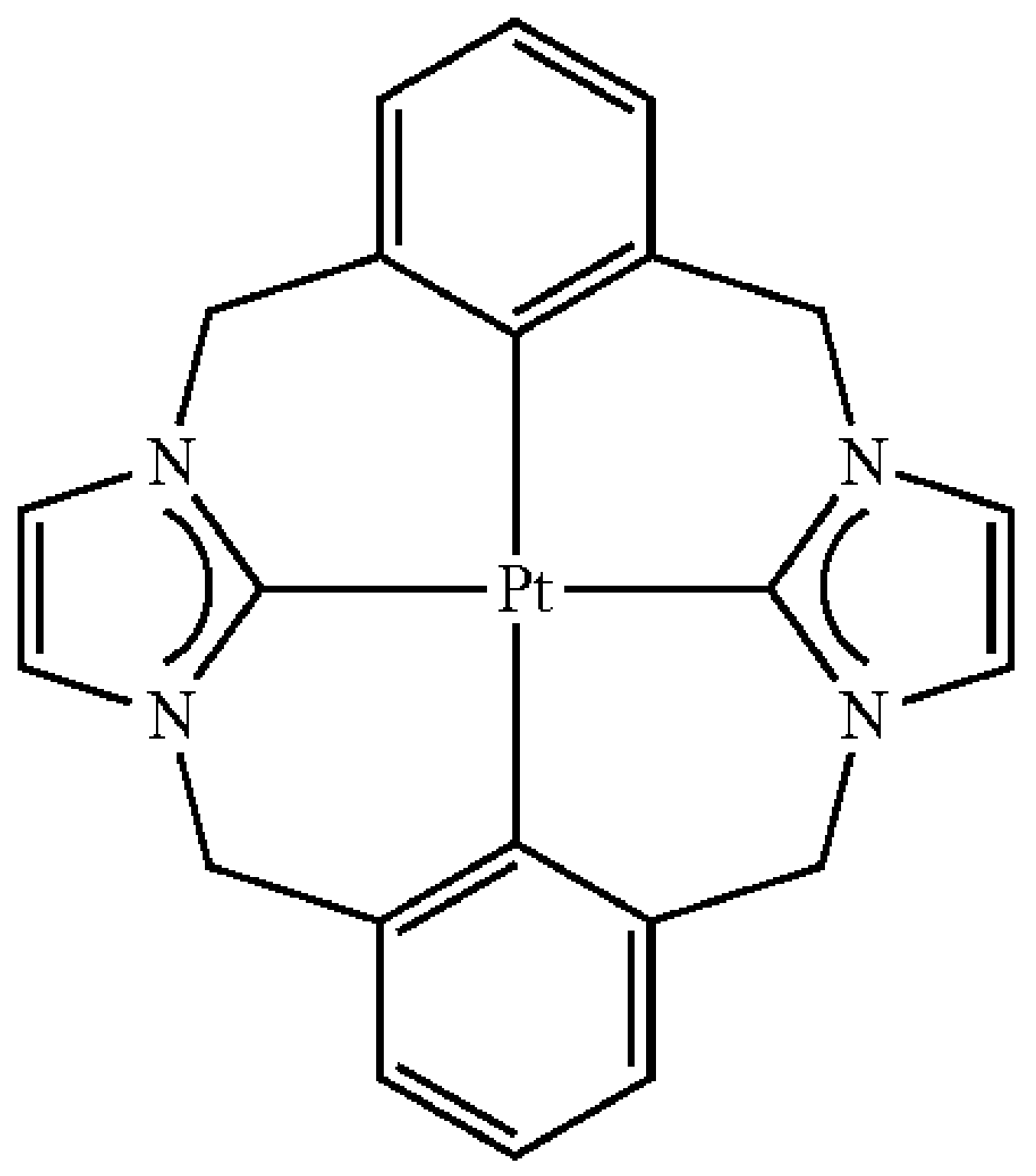
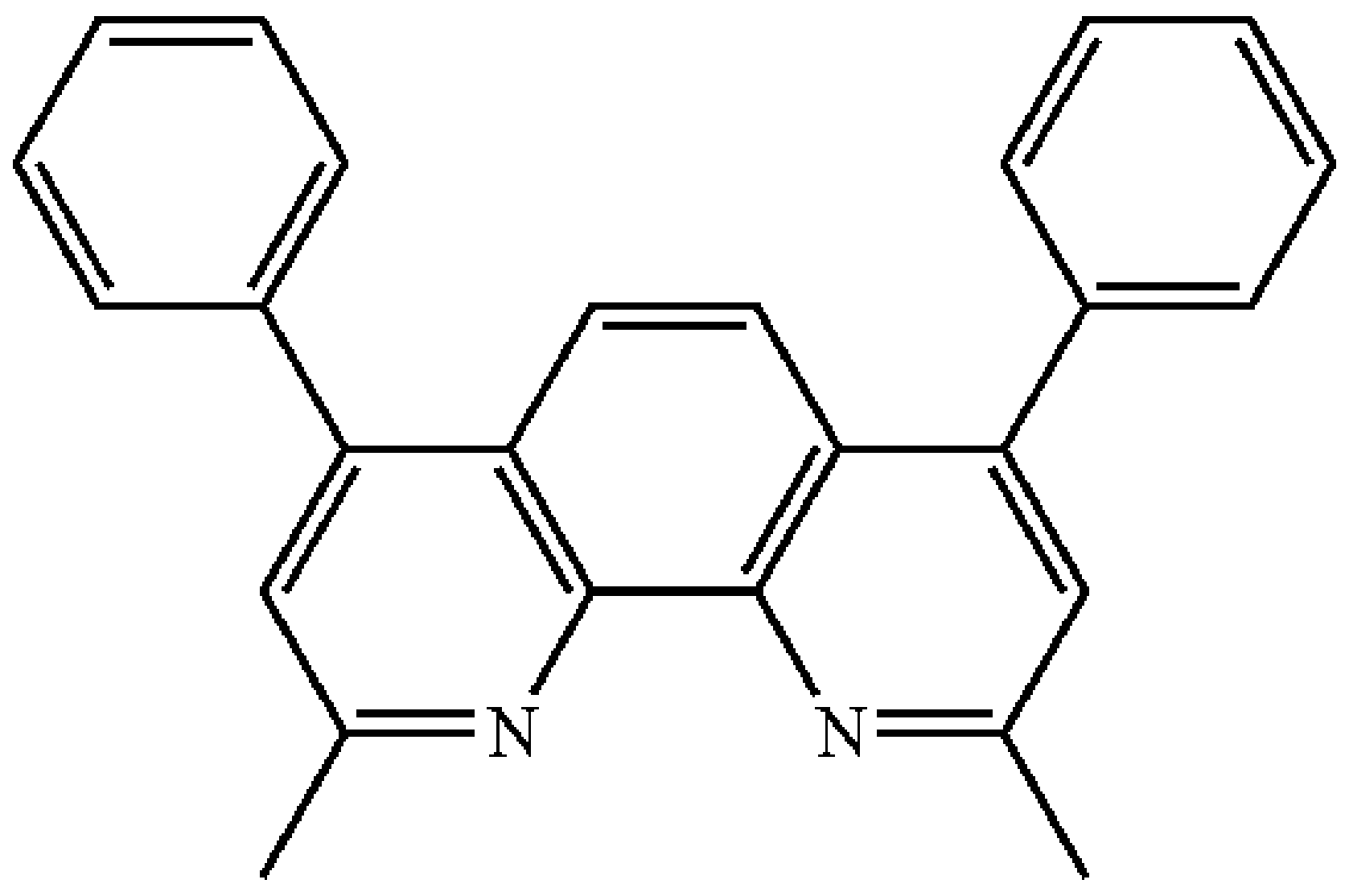
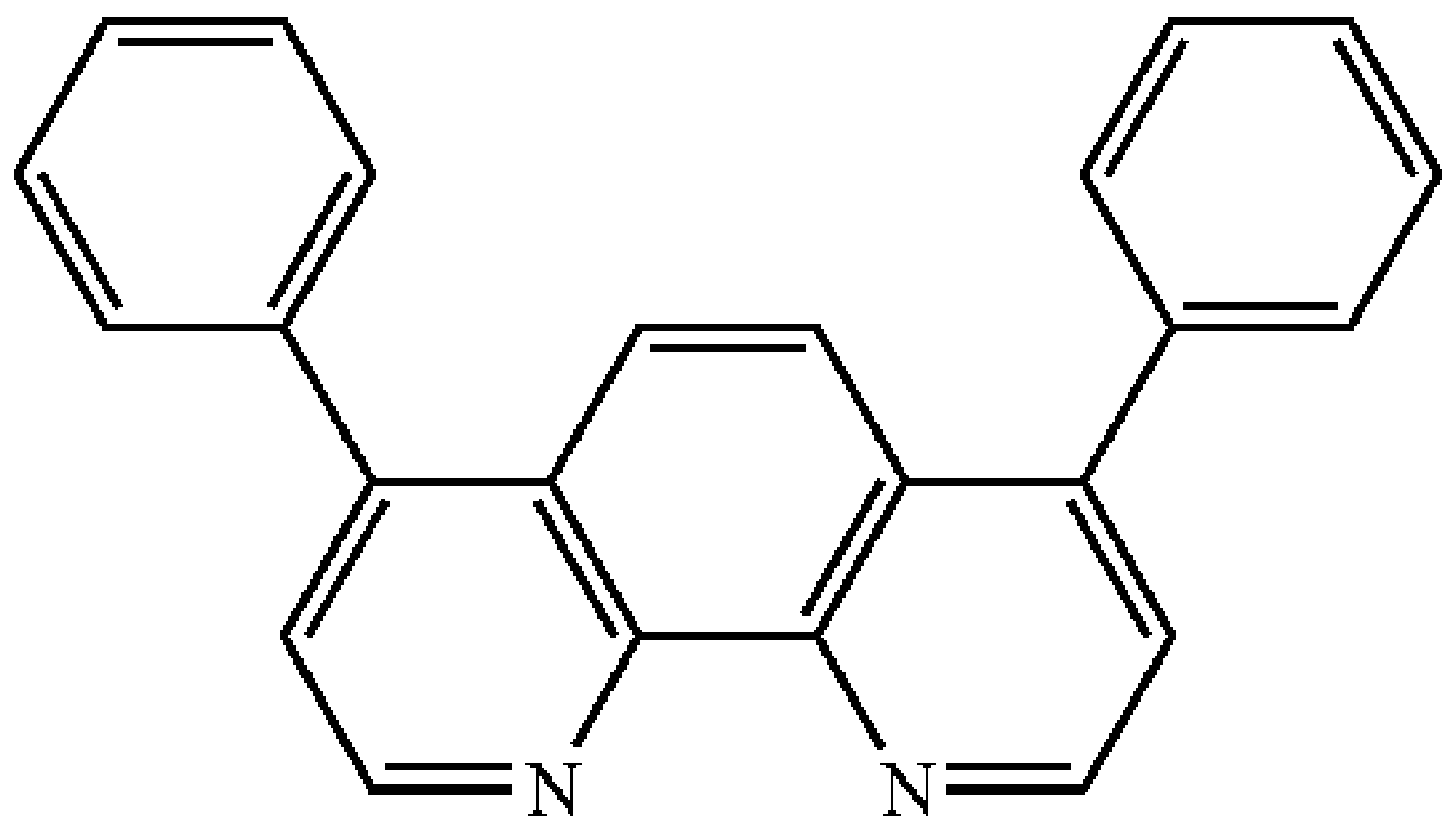
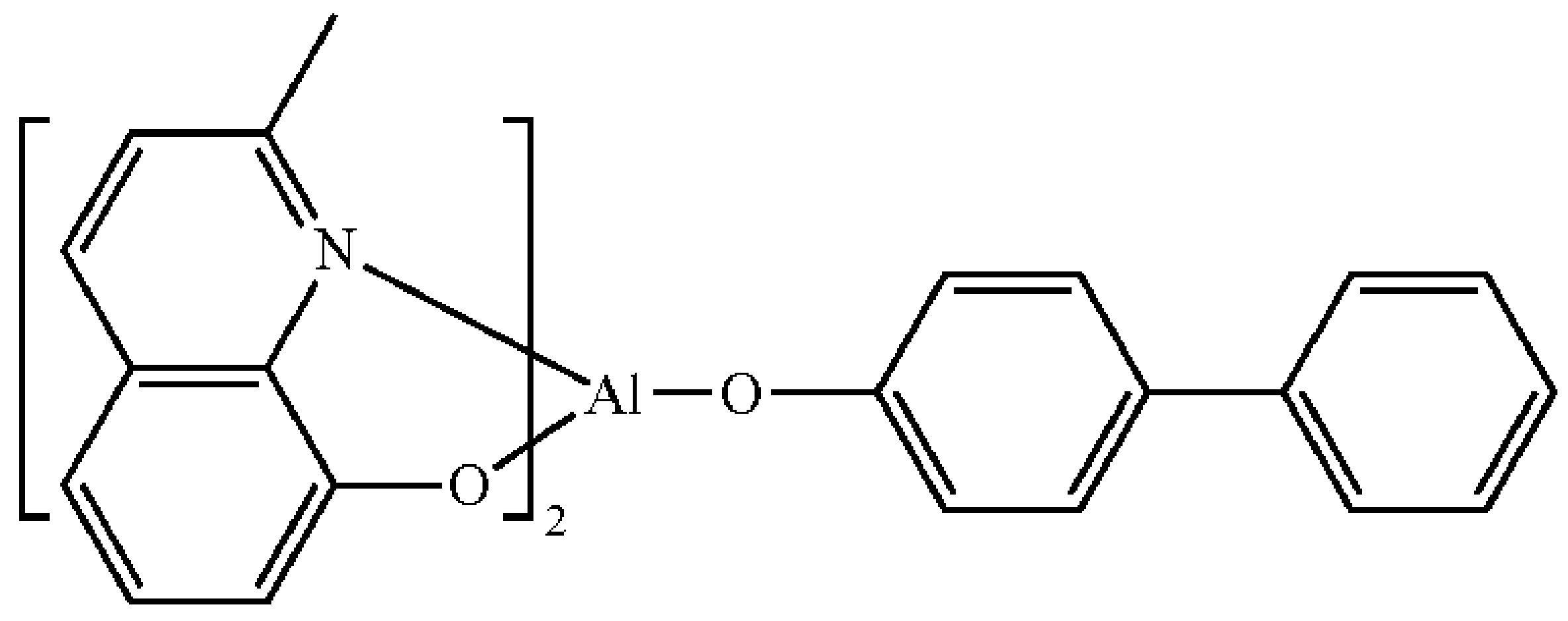
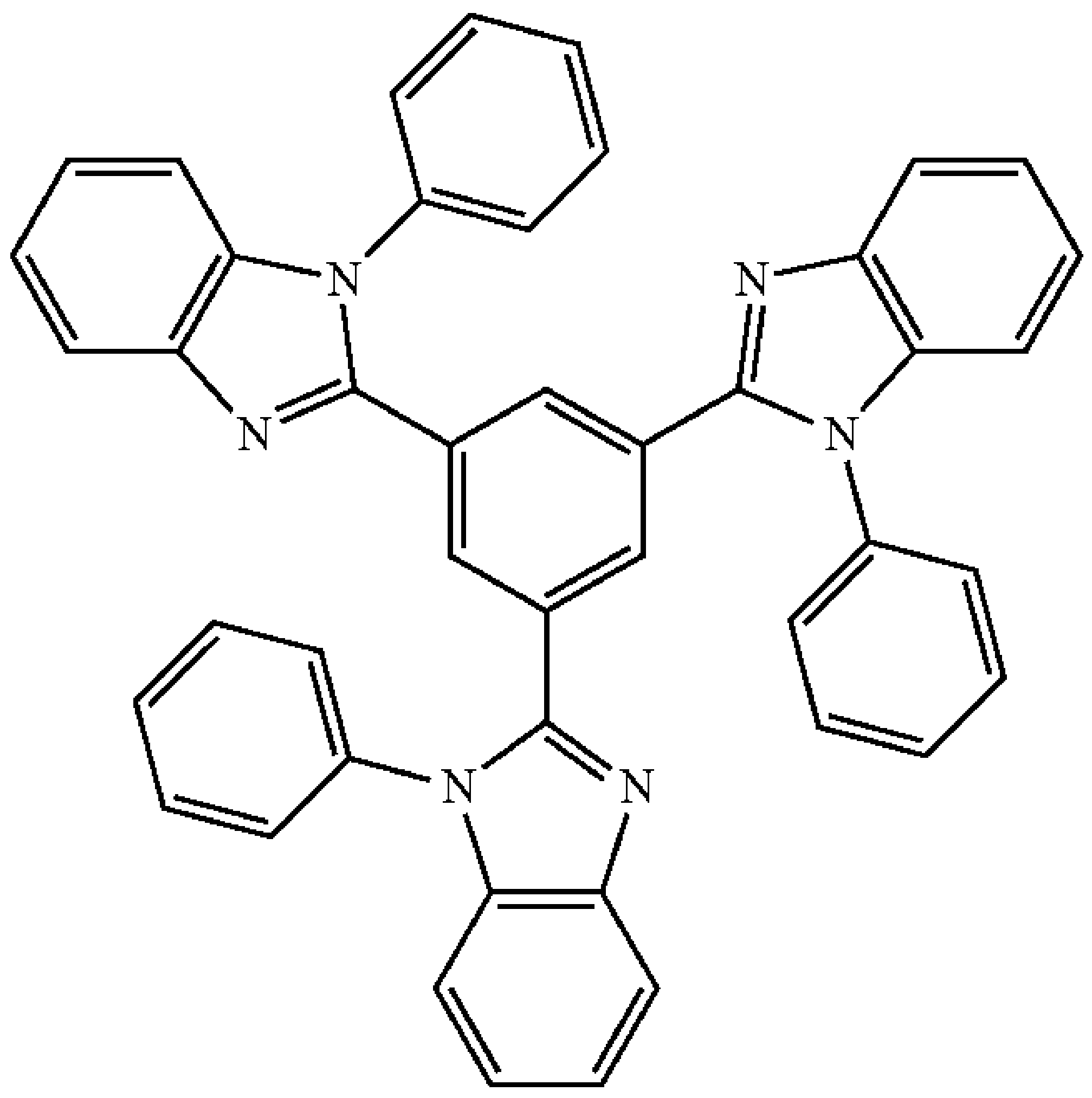
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
Pt tetradentate complexes with at least one metal-carbene bond		U.S. Pat. No. 7,655,323
	Exciton/hole blocking layer materials	
Bathocuprine compounds (e.g., BCP, BPhen)		Appl. Phys. Lett. 75, 4 (1999)
		Appl. Phys. Lett. 79, 449 (2001)
Metal 8-hydroxyquinolates (e.g., BAlq)		Appl. Phys. Lett. 81, 162 (2002)
5-member ring electron deficient heterocycles such as triazole, oxadiazole, imidazole, benzoimidazole		Appl. Phys. Lett. 81, 162 (2002)

TABLE 4-continued

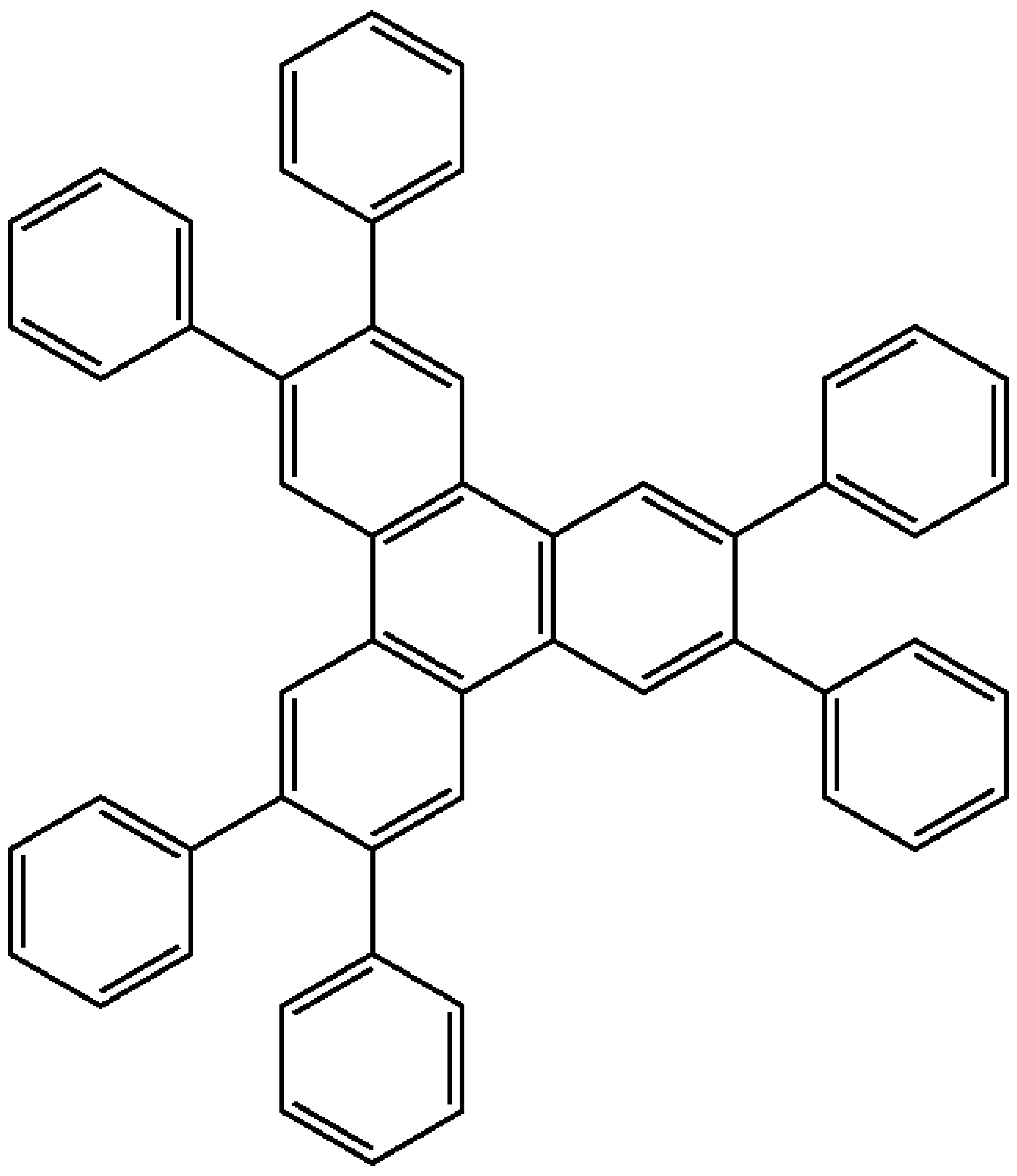
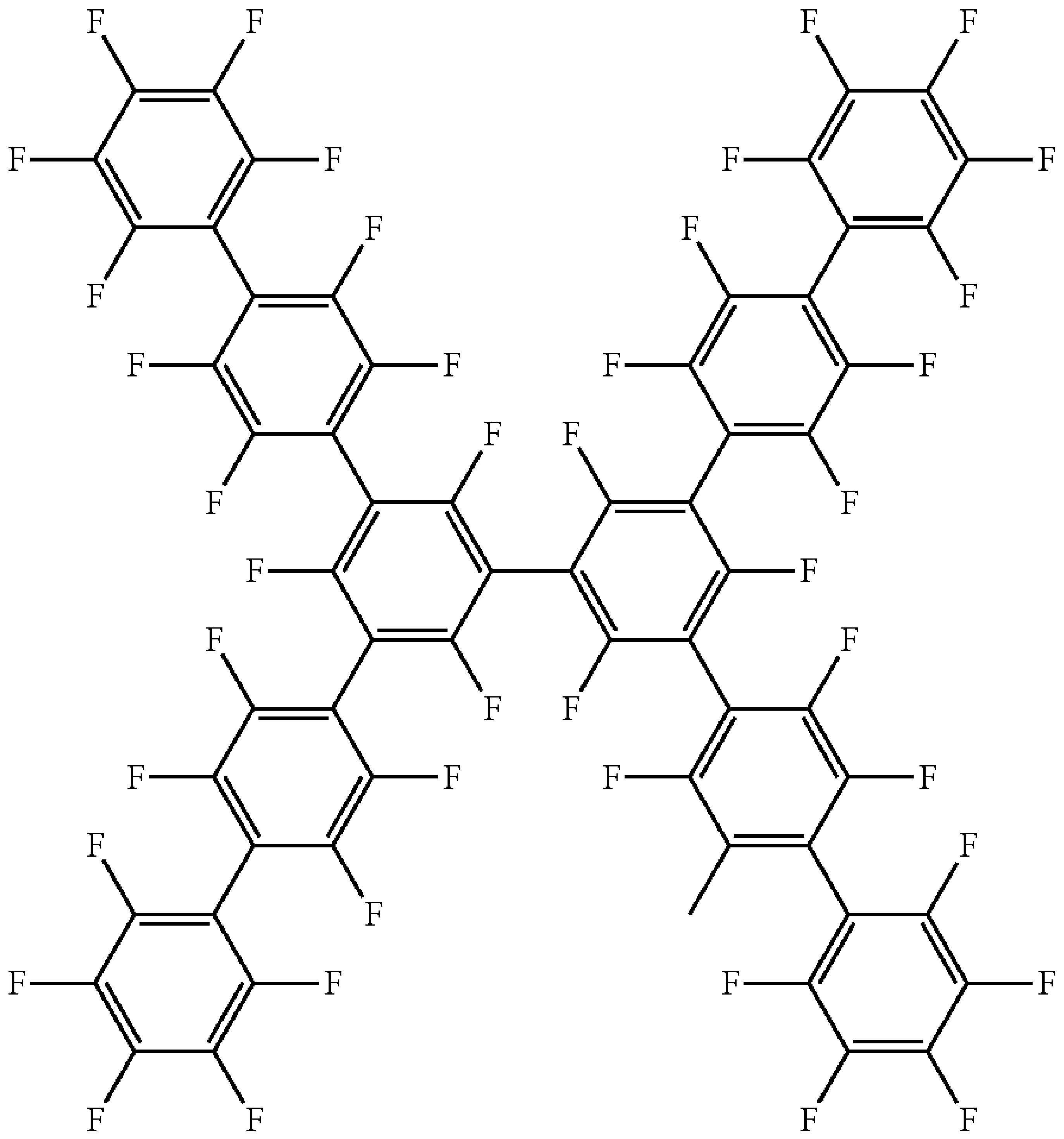
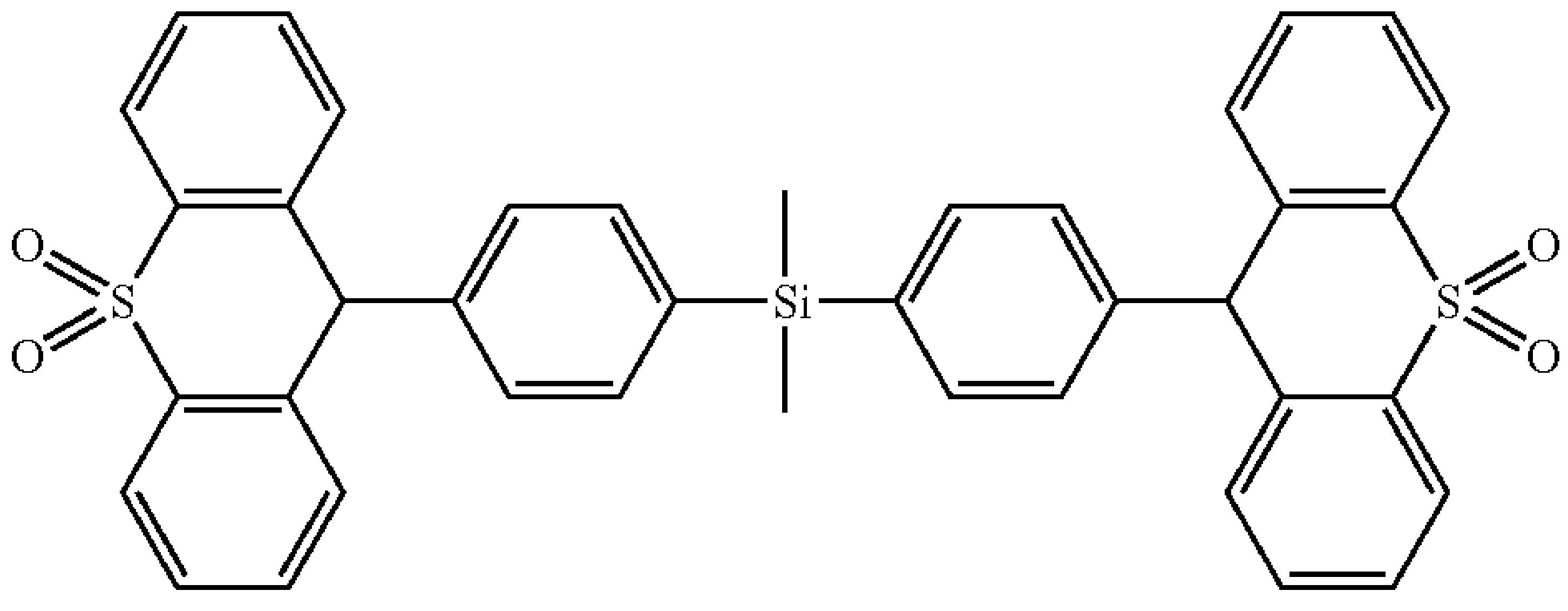
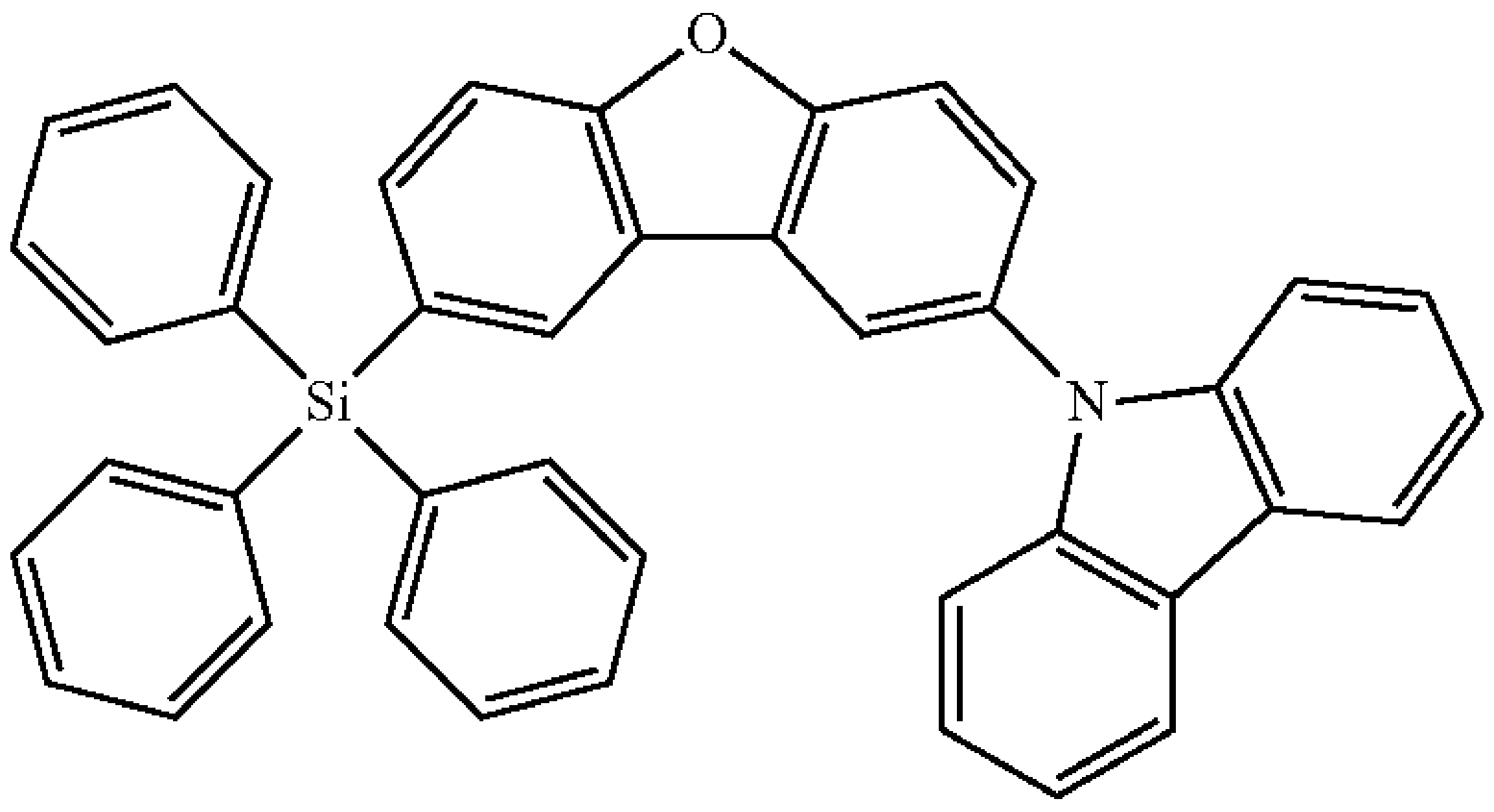
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triphenylene compounds		US20050025993
Fluorinated aromatic compounds		Appl. Phys. Lett. 79, 156 (2001)
Phenothiazine-S-oxide		WO2008132085
Silylated five-membered nitrogen, oxygen, sulfur or phosphorus dibenzoheterocycles		WO2010079051

TABLE 4-continued

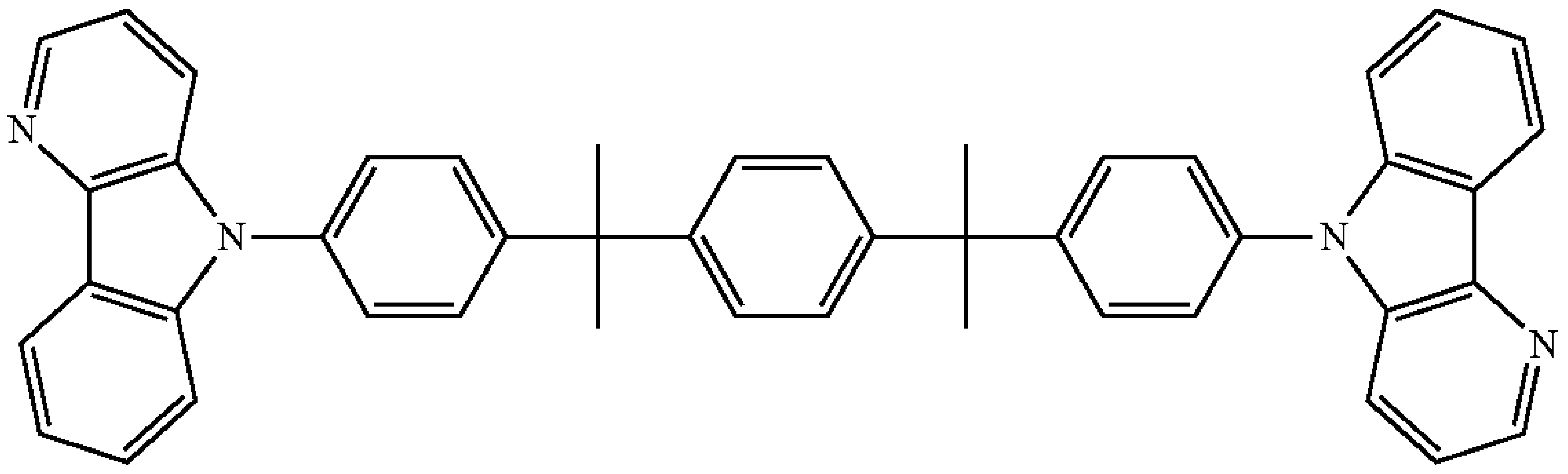
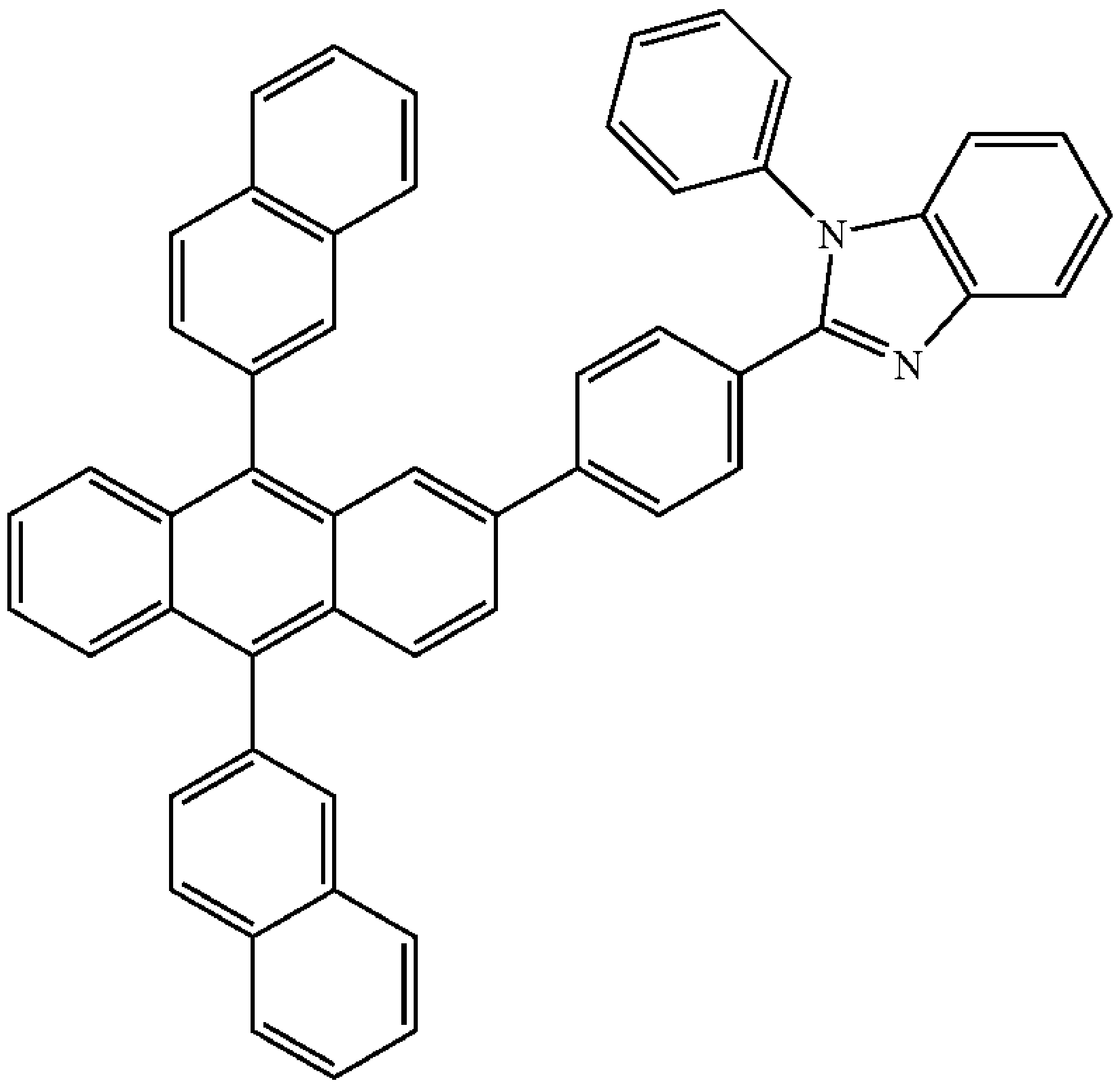
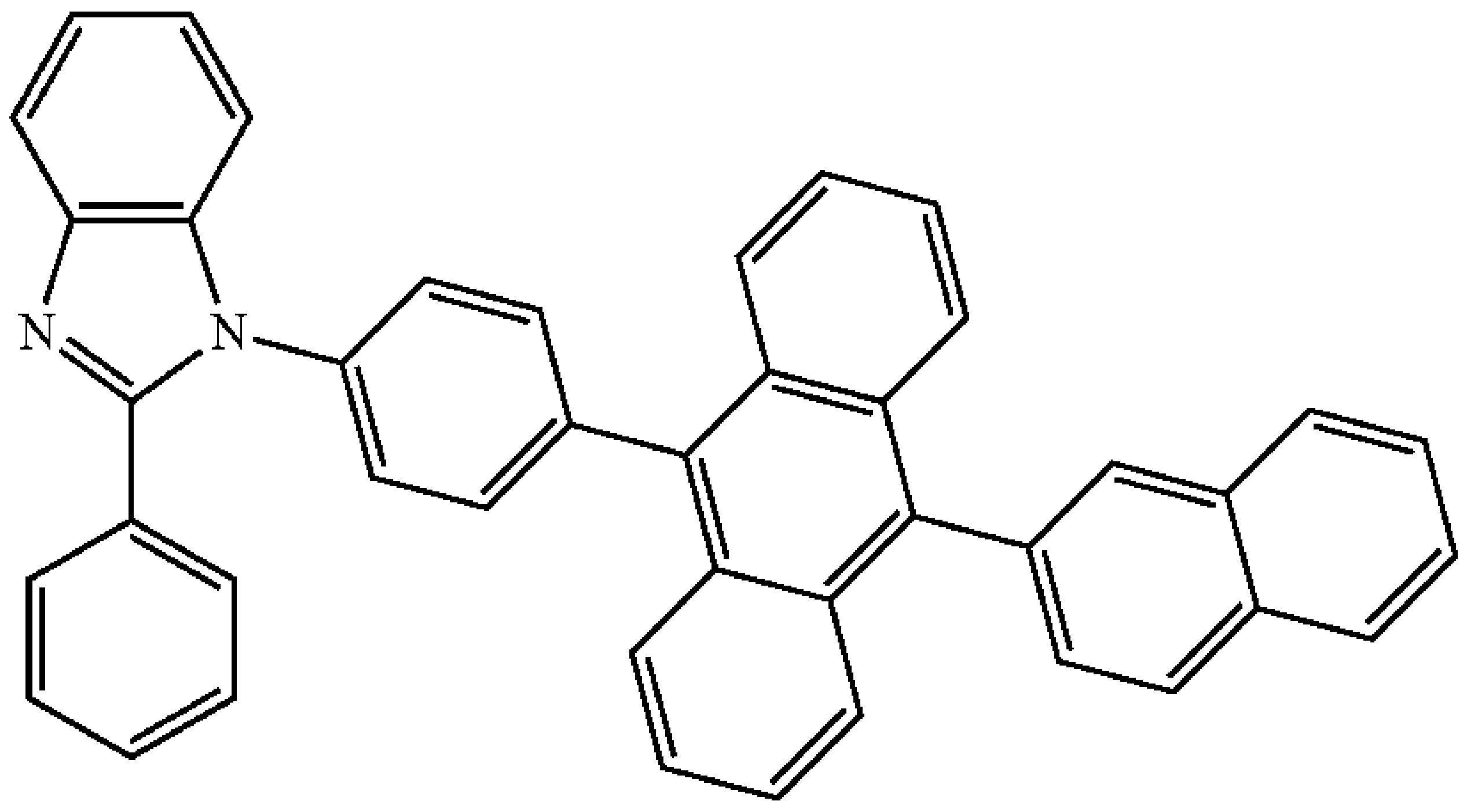
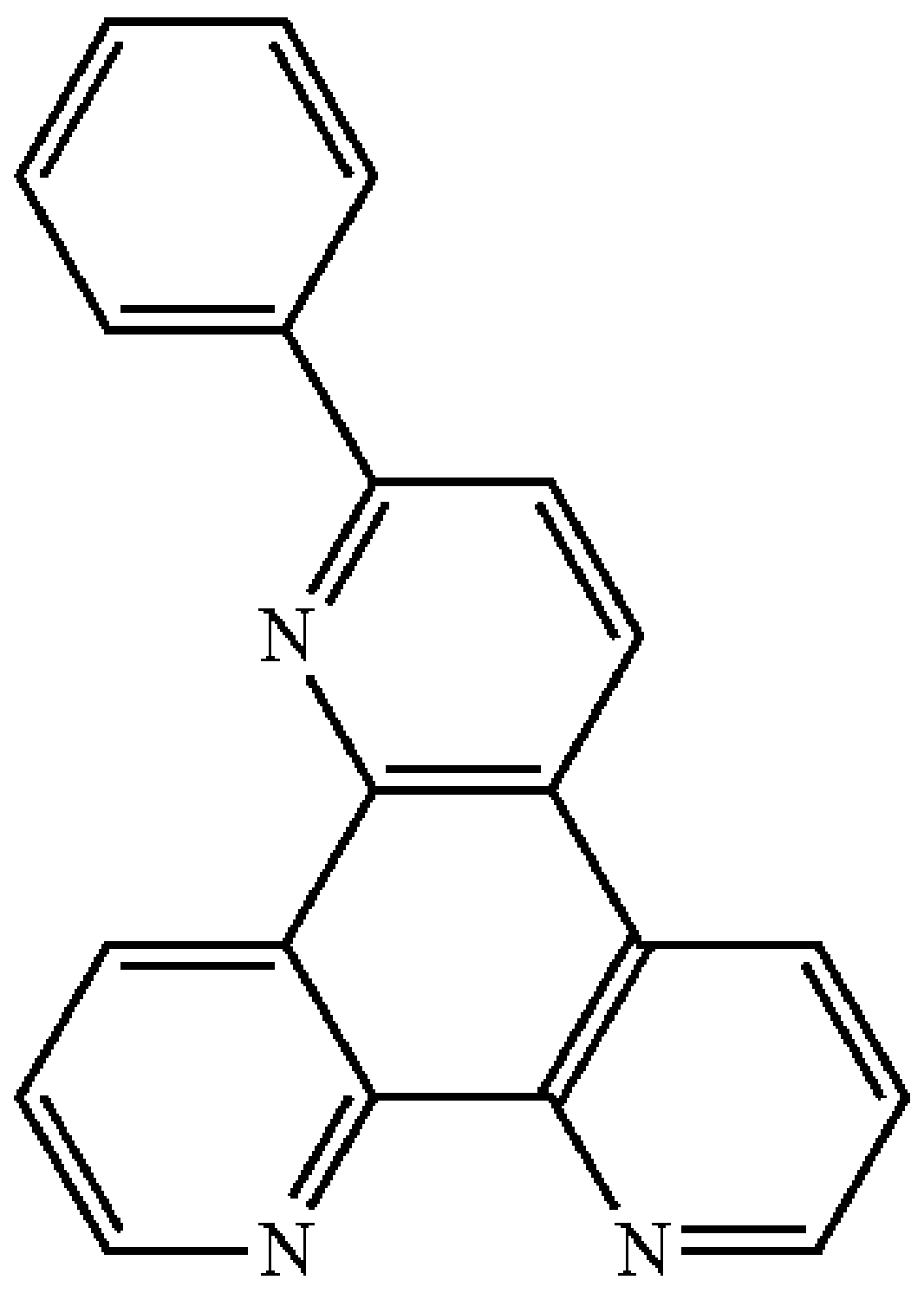
MATERIAL	EXAMPLES OF MATERIAL	PUB- LICATIONS
Aza-carbazoles		US20060121308
	Electron transporting materials	
Anthracene-benzoimidazole compounds		WO2003060956
		US20090179554
Aza triphenylene derivatives		US20090115316

TABLE 4-continued

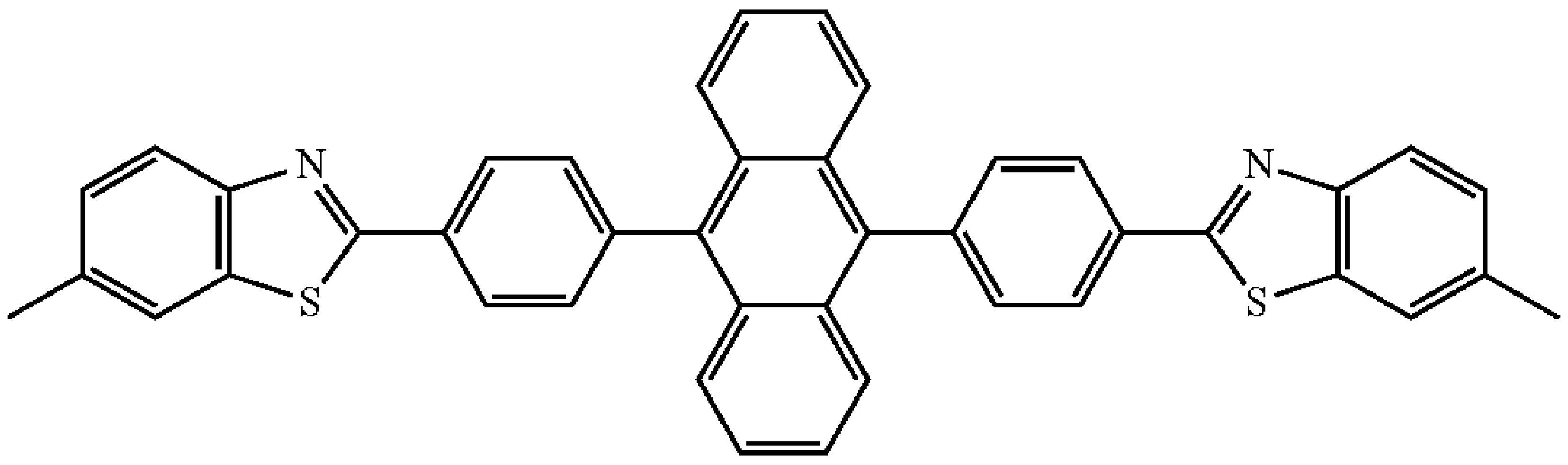
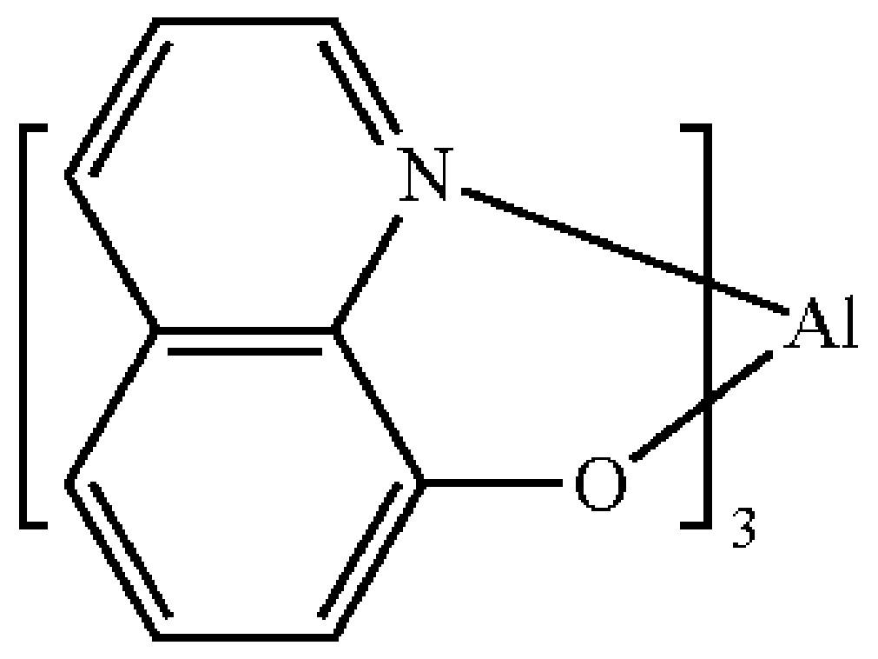
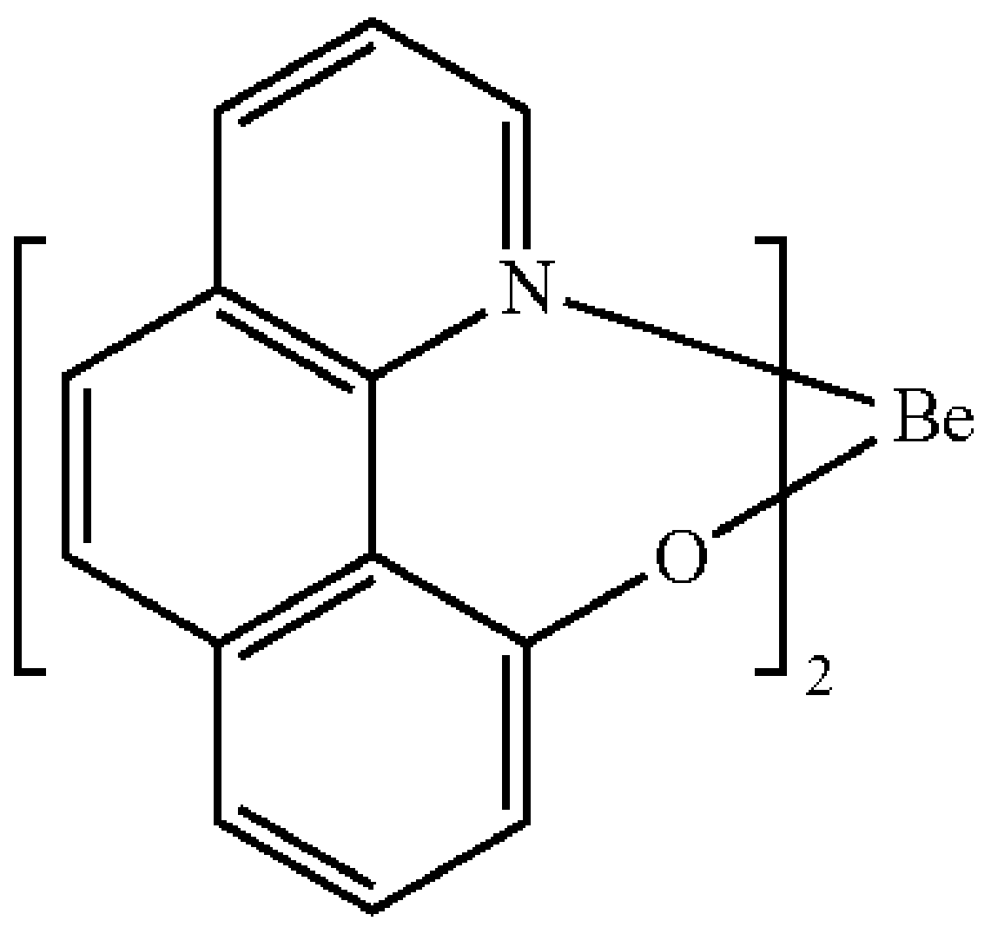
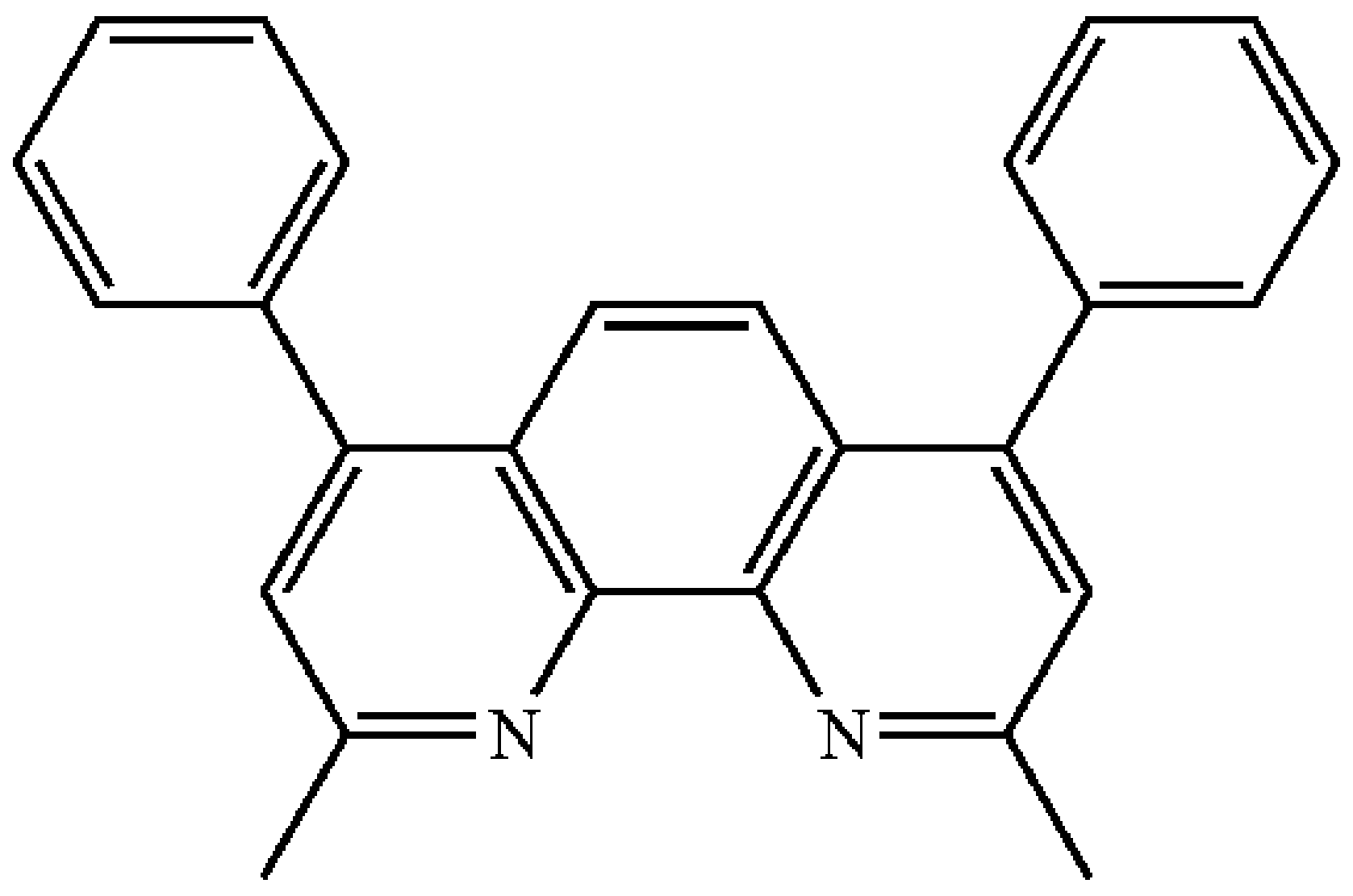
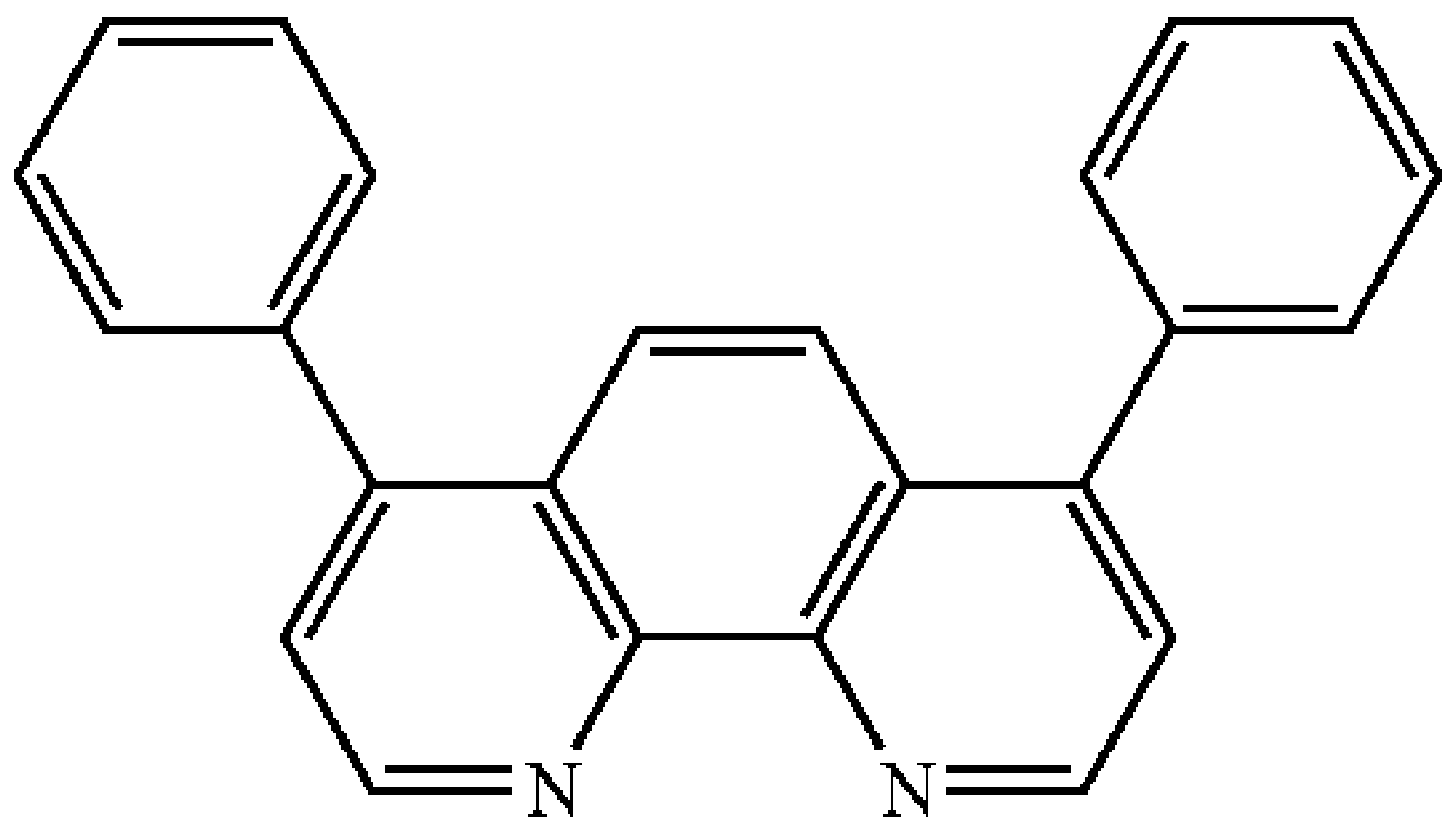
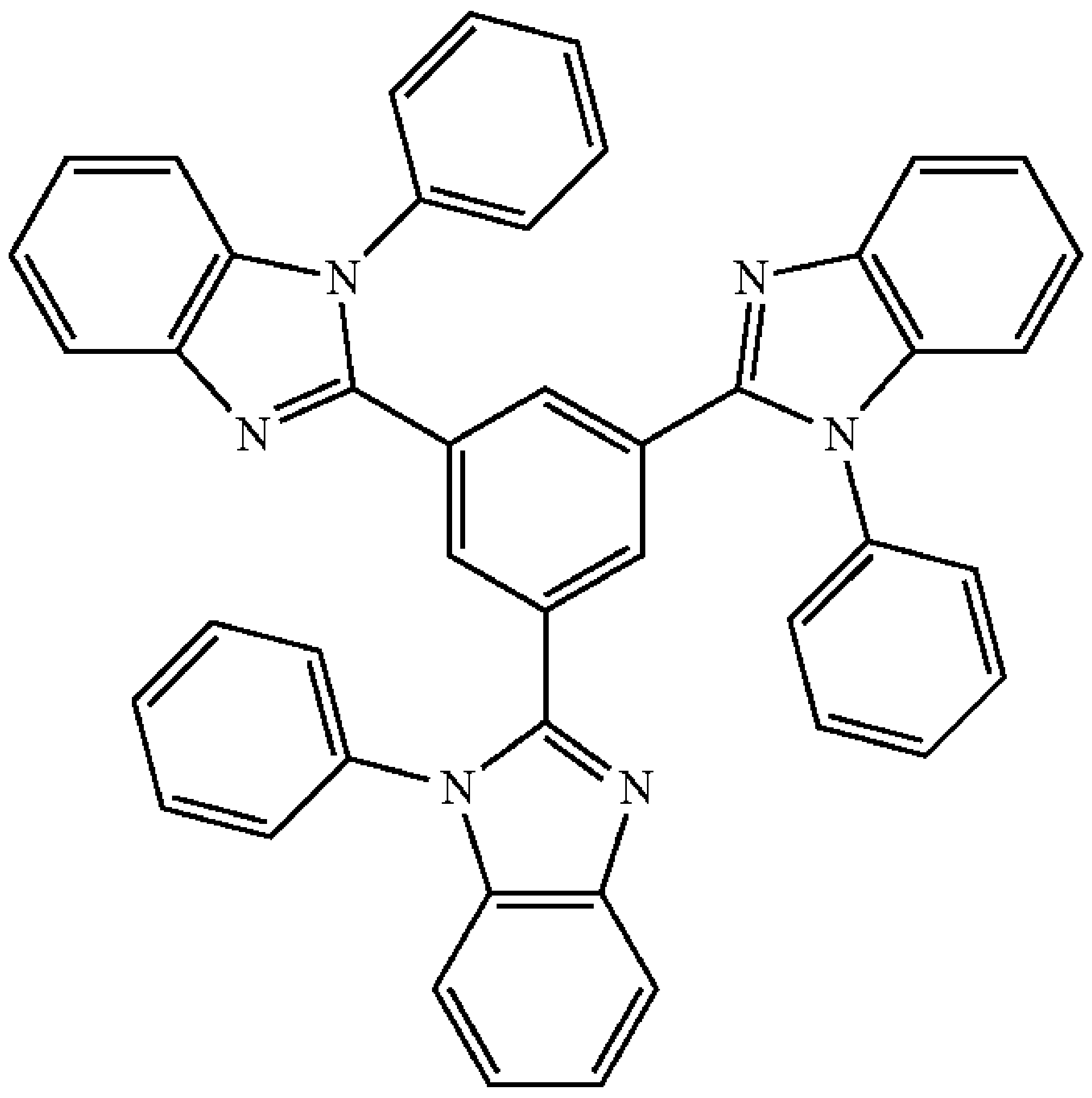
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
Anthracene-benzothiazole compounds		Appl. Phys. Lett. 89, 063504 (2006)
Metal 8-hydroxyquinolates (e.g., Alq_3, Zrq_4)		Appl. Phys. Lett. 51, 913 (1987) U.S. Pat. No. 7,230,107
Metal hydroxy-benoquinolates		Chem. Lett. 5, 905 (1993)
Bathocuprine compounds such as BCP, BPhen, etc		Appl. Phys. Lett. 91, 263503 (2007)
		Appl. Phys. Lett. 79, 449 (2001)
5-member ring electron deficient heterocycles (e.g., triazole, oxadiazole, imidazole, benzoimidazole)		Appl. Phys. Lett. 74, 865 (1999)

TABLE 4-continued

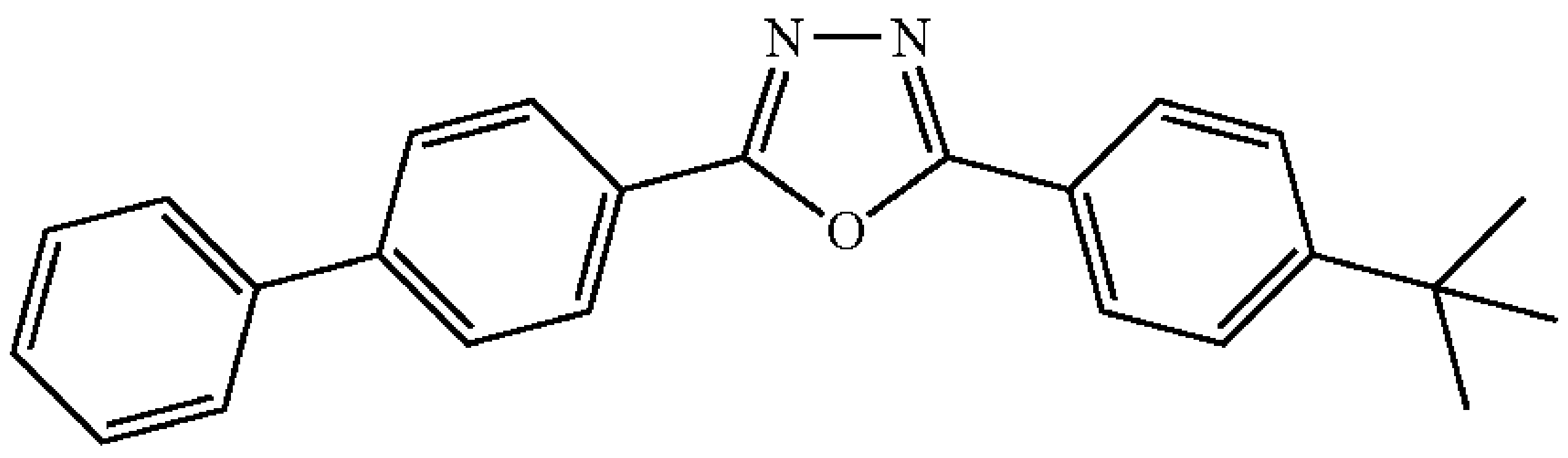
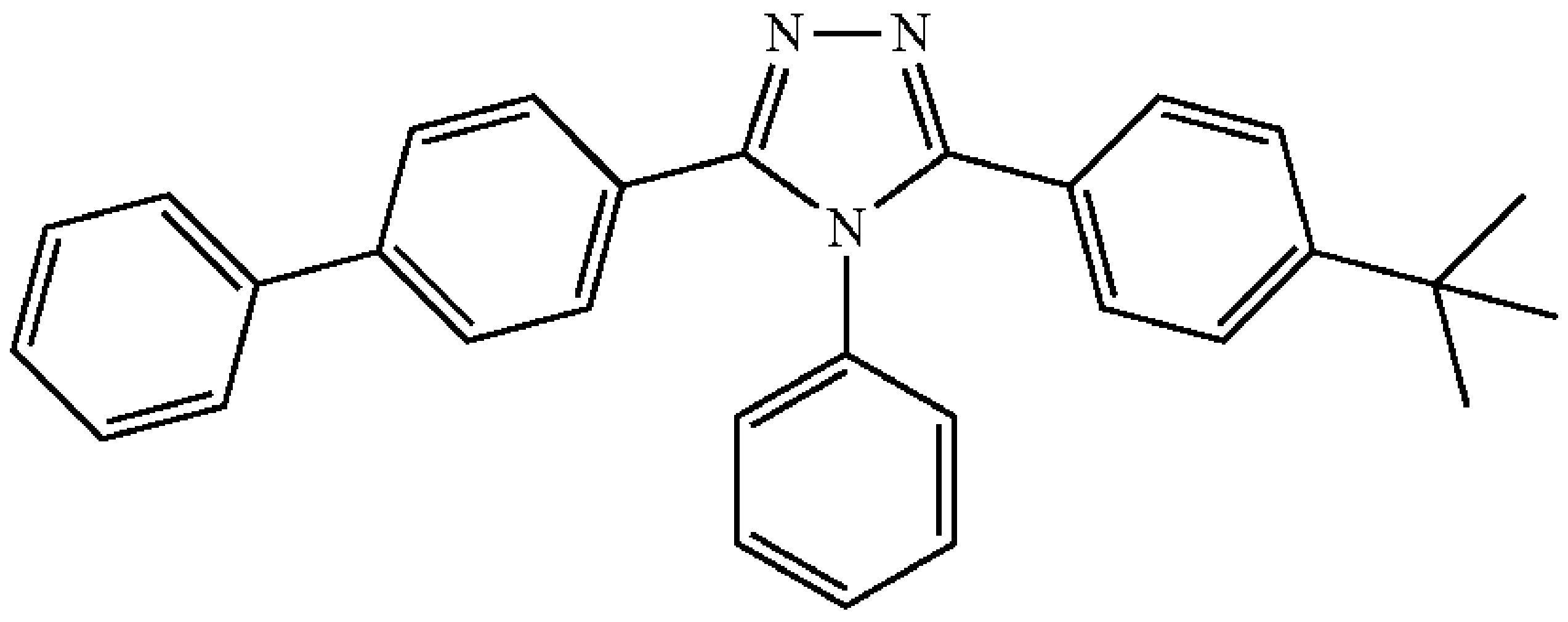
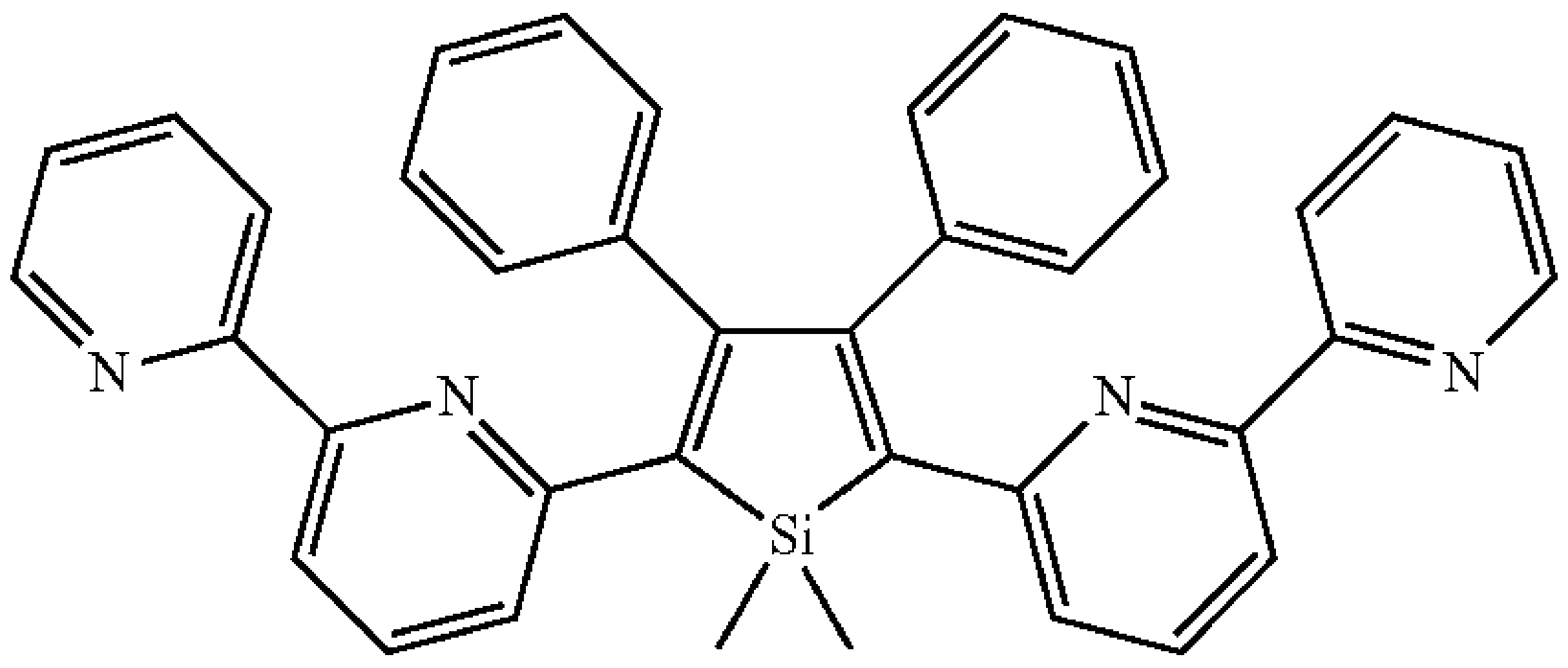
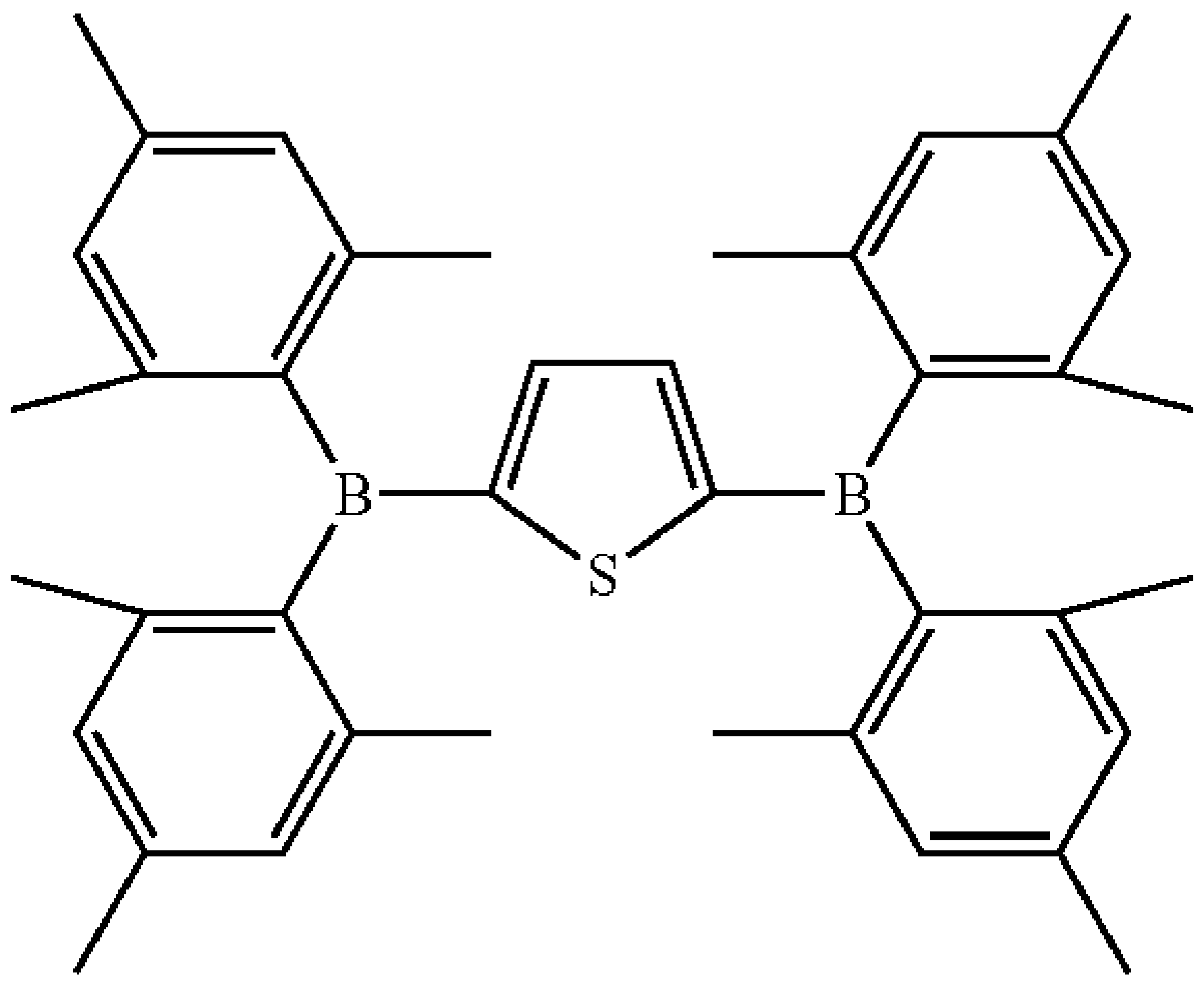
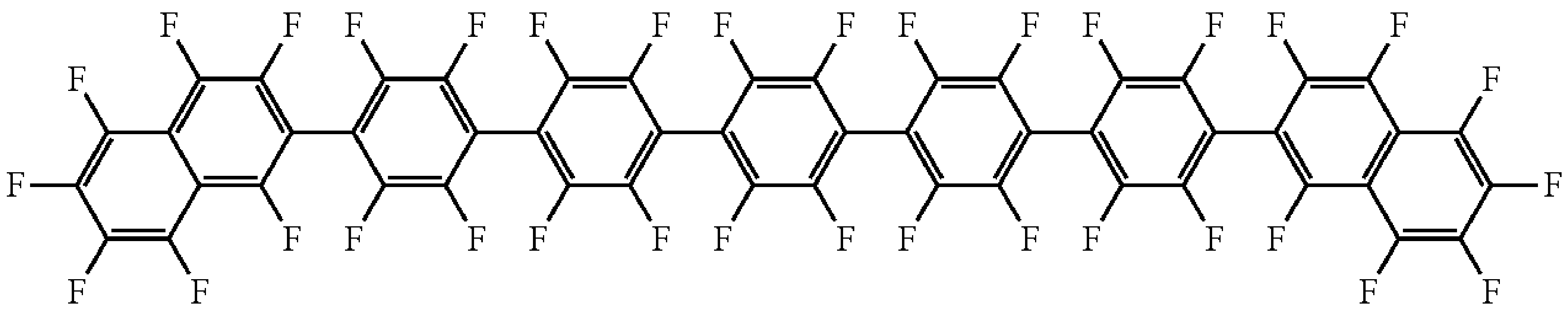
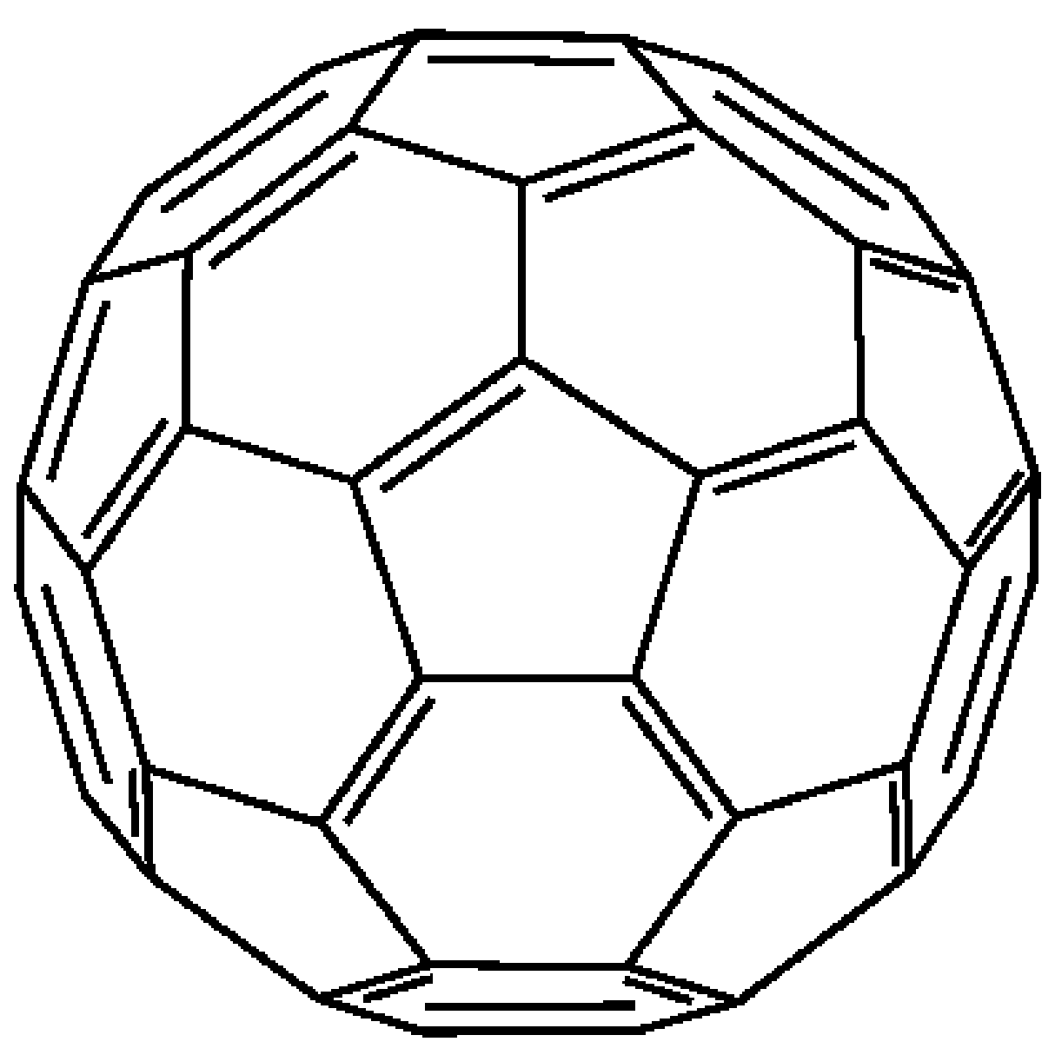
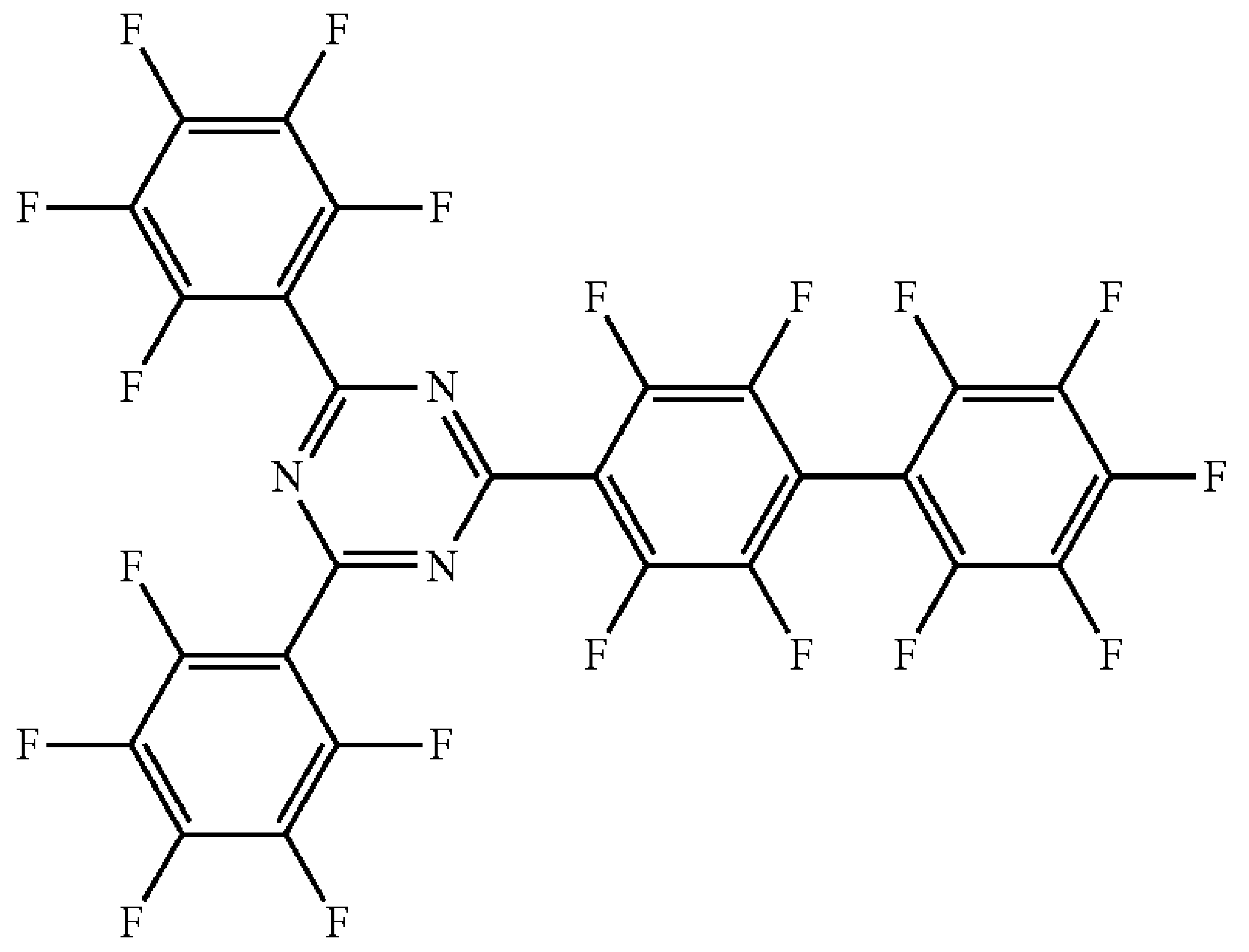
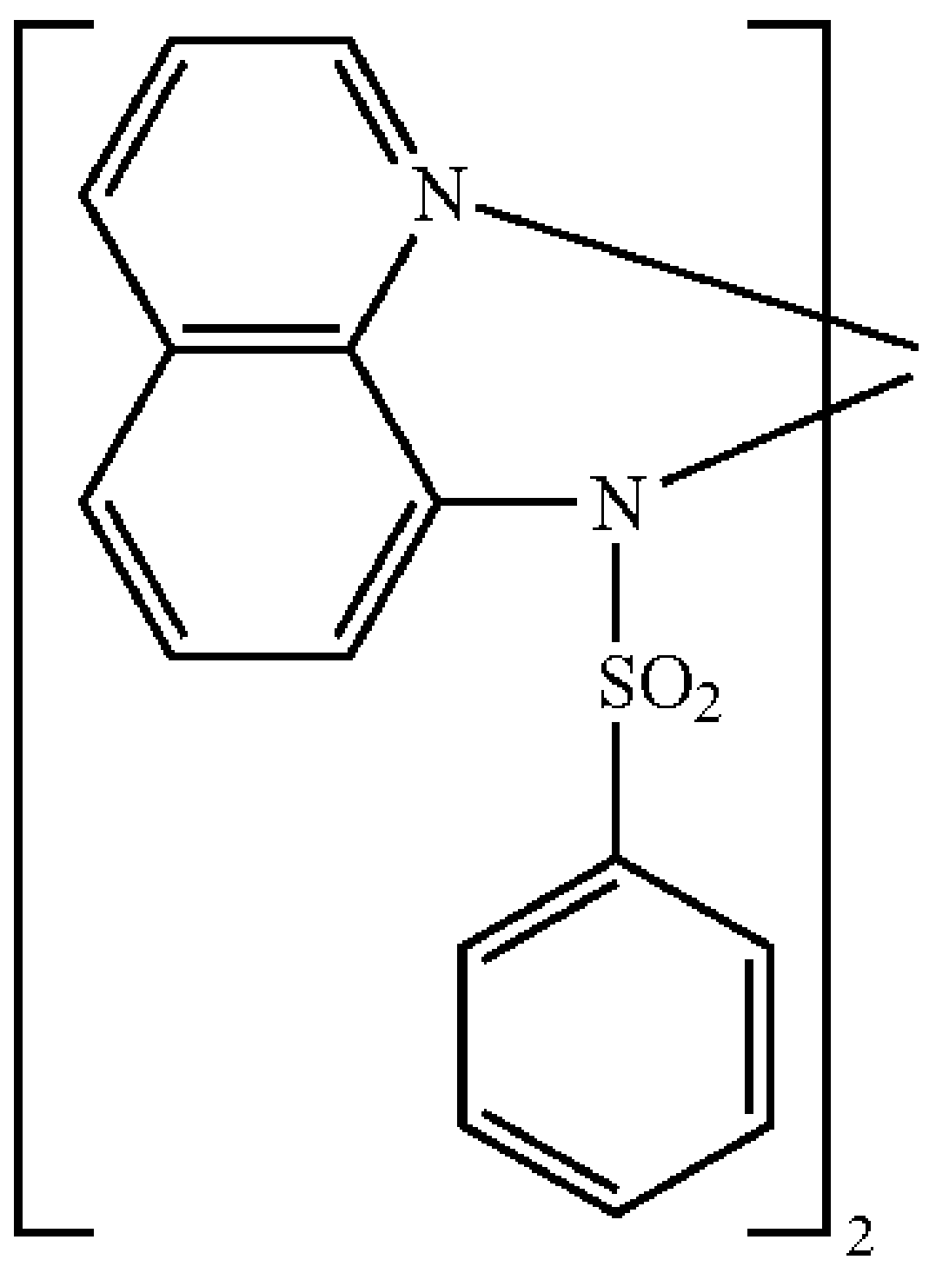
MATERIAL	EXAMPLES OF MATERIAL	PUB-LICATIONS
		Appl. Phys. Lett. 55, 1489 (1989)
		Jpn. J. Apply. Phys. 32, L917 (1993)
Silole compounds		Org. Electron. 4, 113 (2003)
Arylborane compounds		J. Am. Chem. Soc. 120, 9714 (1998)
Fluorinated aromatic compounds		J. Am. Chem. Soc. 122, 1832 (2000)
Fullerene (e.g., C60)		US20090101870

TABLE 4-continued

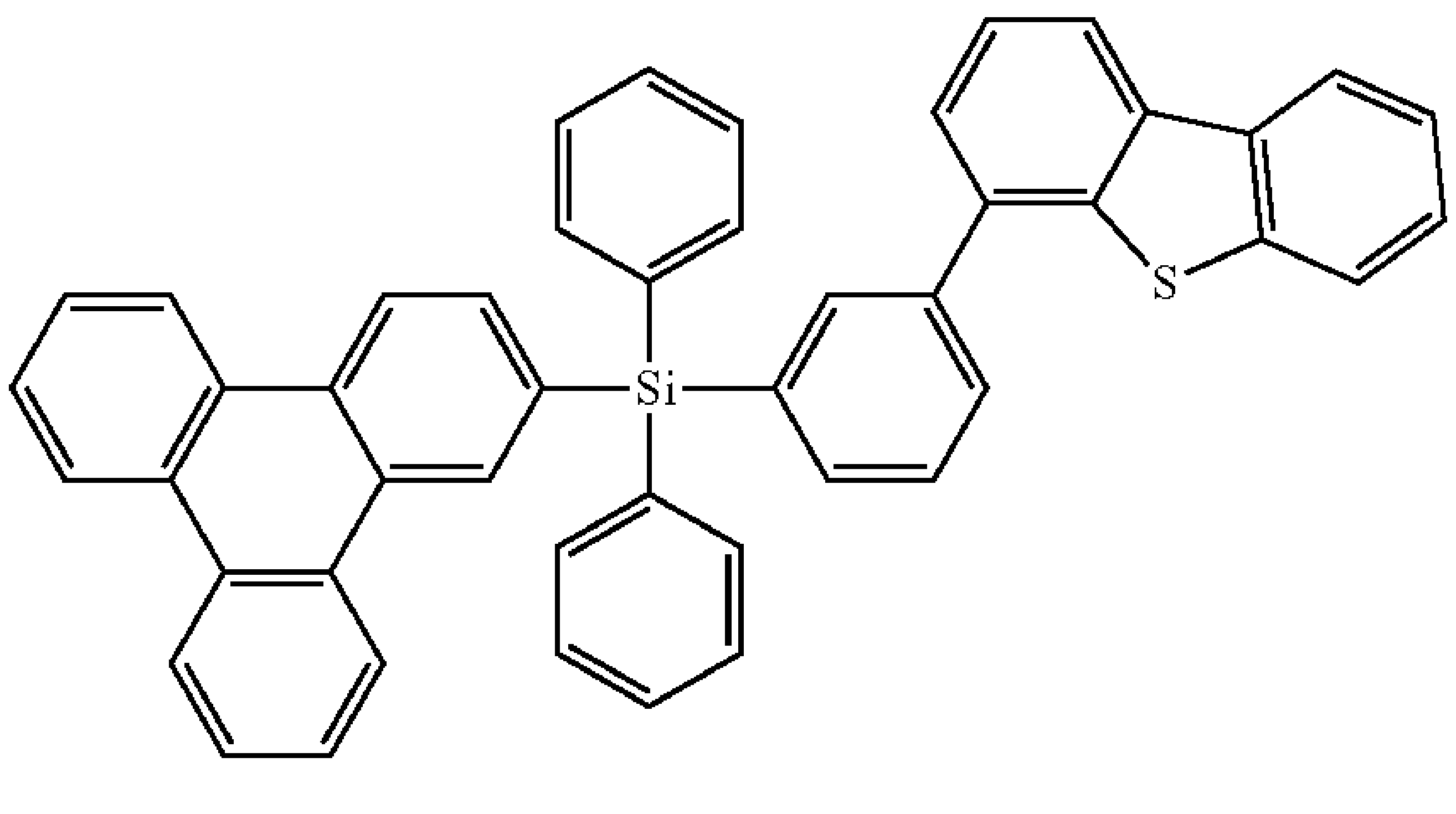
MATERIAL	EXAMPLES OF MATERIAL	PUBLICATIONS
Triazine complexes		US20040036077
Zn (N^N) complexes		U.S. Pat. No. 6,528,187

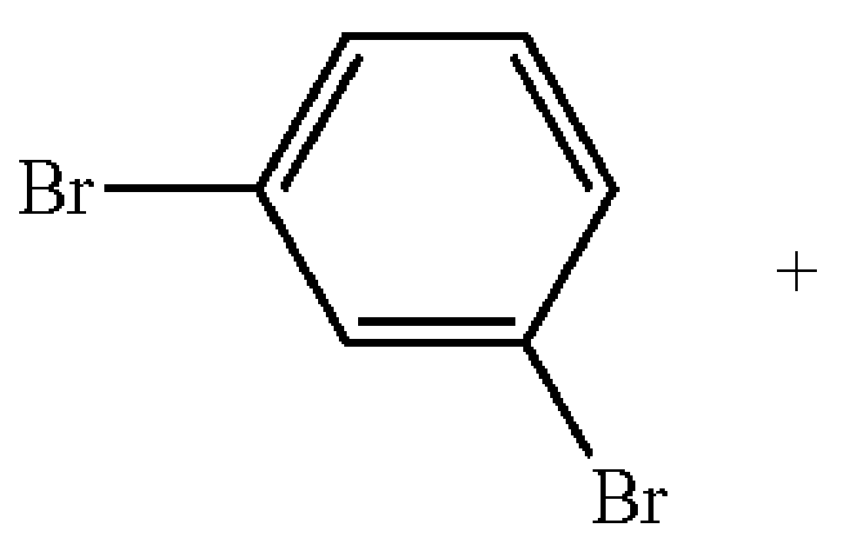
EXPERIMENTAL

Chemical abbreviations used throughout this document are as follows: dba is dibenzylideneacetone, EtOAc is ethyl acetate, dppf is 1,1'-bis(diphenylphosphino)ferrocene, DCM is dichloromethane, SPhos is dicyclohexyl(2',6'-dimethoxy-[1,1'-biphenyl]-3-yl)phosphine, THF is tetrahydrofuran.

Synthesis of Compound 1

Compound 1





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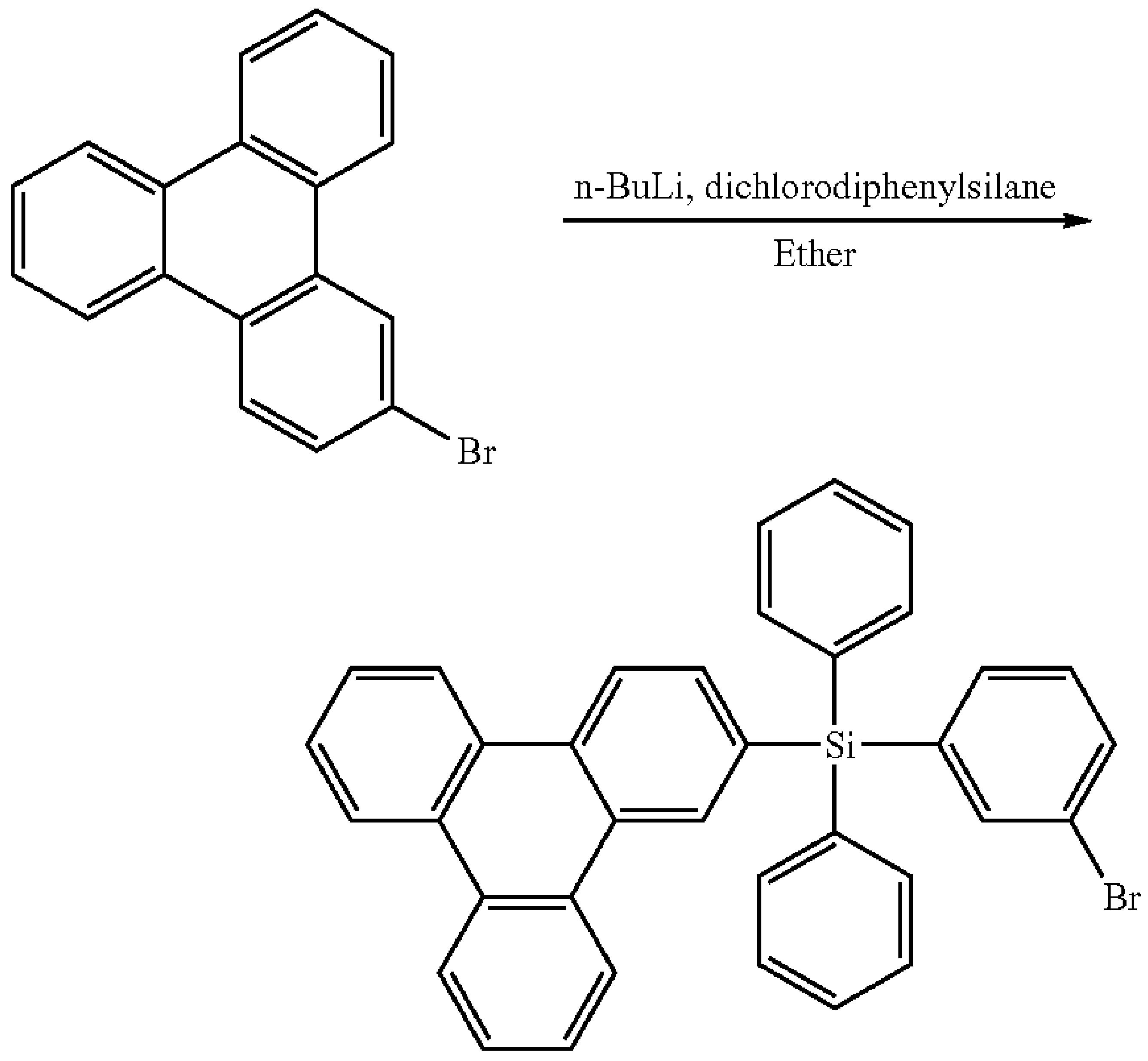
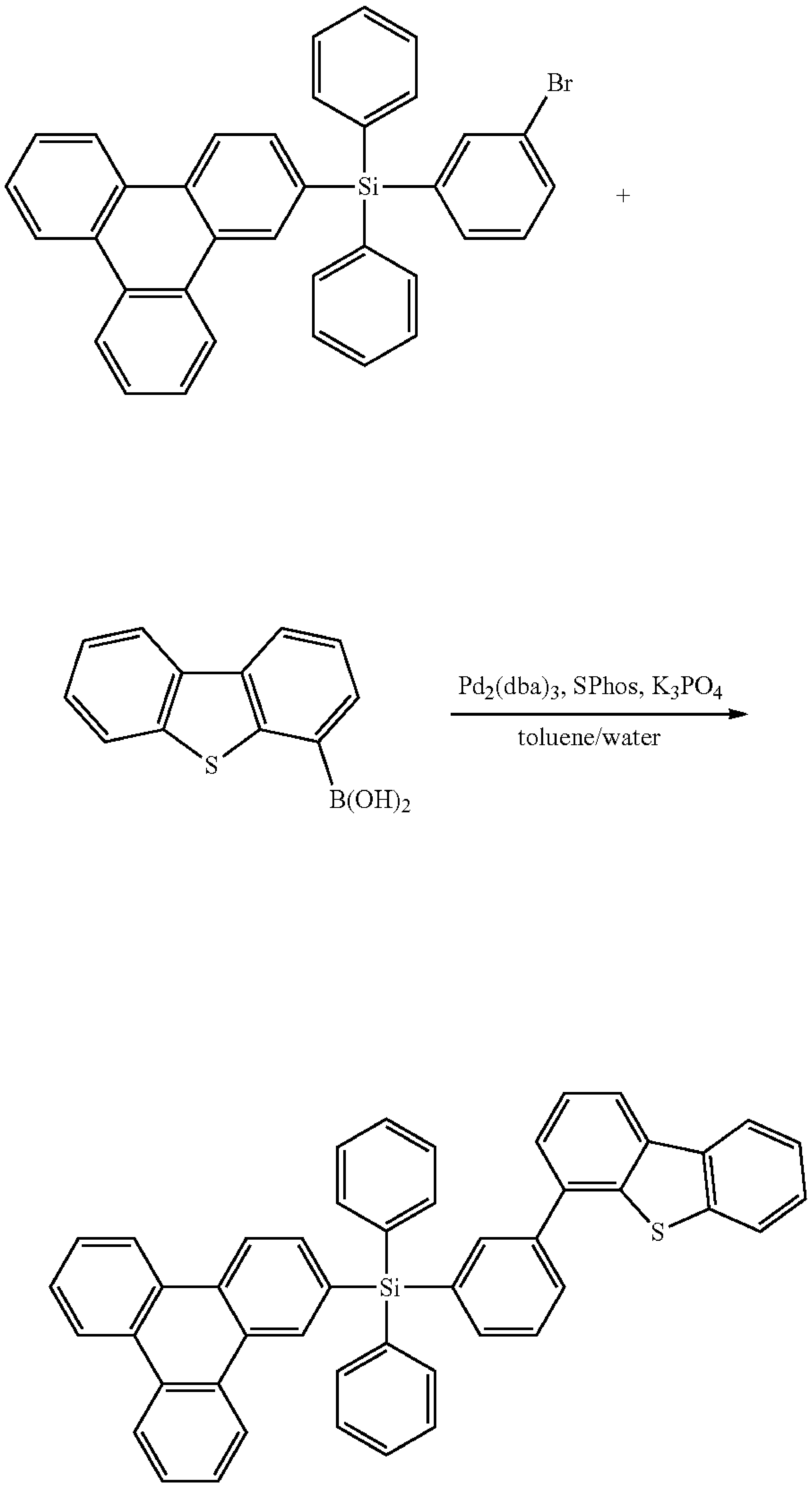


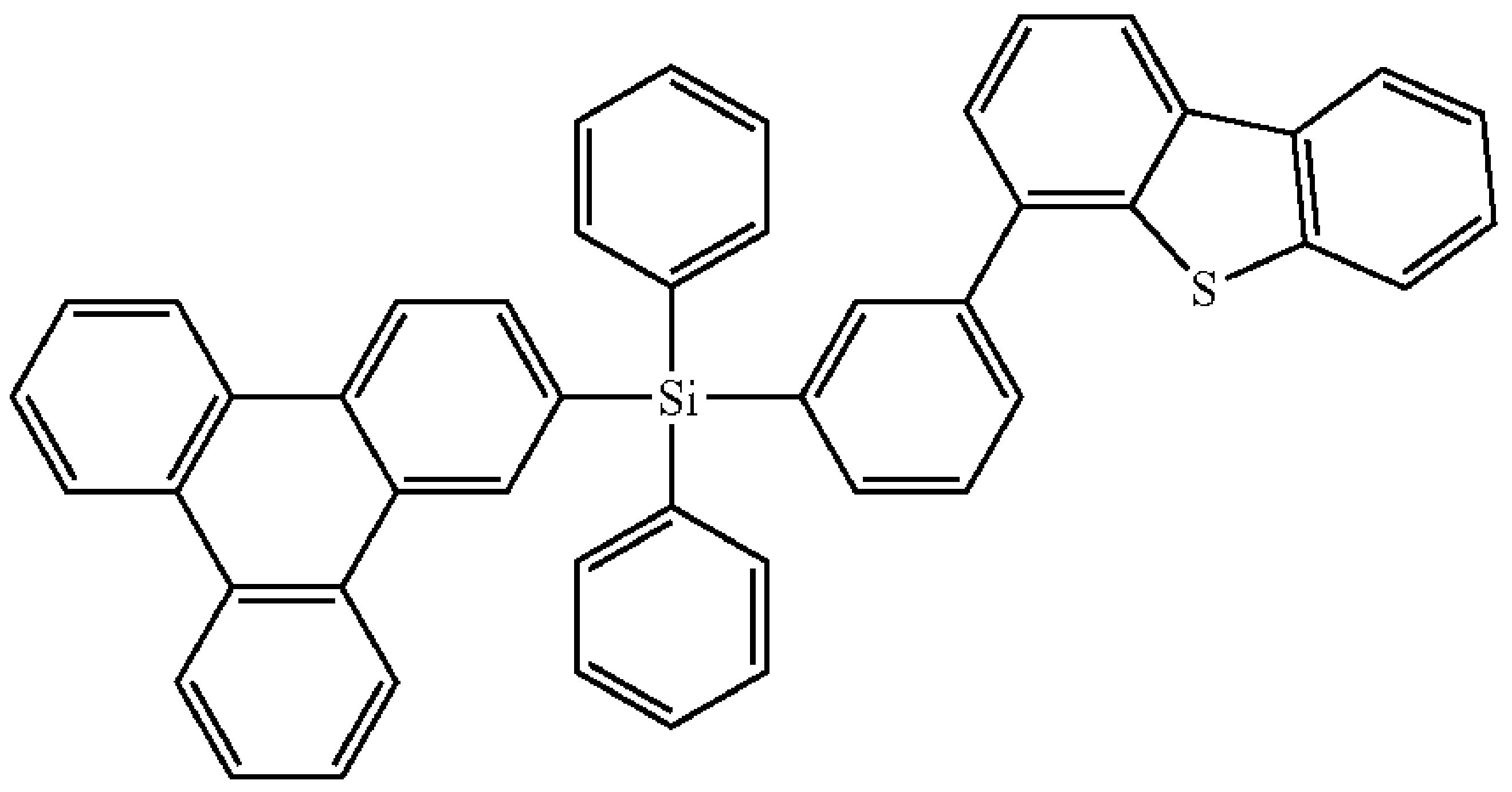
Into a suspension of 2-bromotriphenylene (7.28 g, 23.70 mmol) in ether (50 mL) was added n-butyllithium solution in hexane (14.81 mL, 23.70 mmol) dropwise at −78° C. The suspension was gradually warmed to 0° C. and stirred for 3 hours to yield a solution of triphenylenyllithium. In a separate flask a solution of 3-bromophenyllithium was prepared by dropwise addition of n-butyllithium solution in hexane (14.81 mL, 23.70 mmol) into a solution of 1,3-dibromobenzene (2.87 mL, 23.70 mmol) in ether (50 mL). The solution was stirred at this temperature for 2.5 hours before being transferred into a solution of dichlorodiphenylsilane (4.88 mL, 23.70 mmol) in ether (30 mL) at −78° C. After stirring for another 2 h, the triphenylenyllithium solution prepared above was introduced dropwise into the flask containing the dichlorophenylsilane. The reaction mixture was allowed to gradually warm to room temperature and was stirred overnight. The mixture was quenched with water and the organic phase was isolated. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane/DCM (85/15, v/v) as eluent to yield (3-bromophenyl)diphenyl(triphenylen-2-yl)silane (8.5 g, 75%) as a white powder.

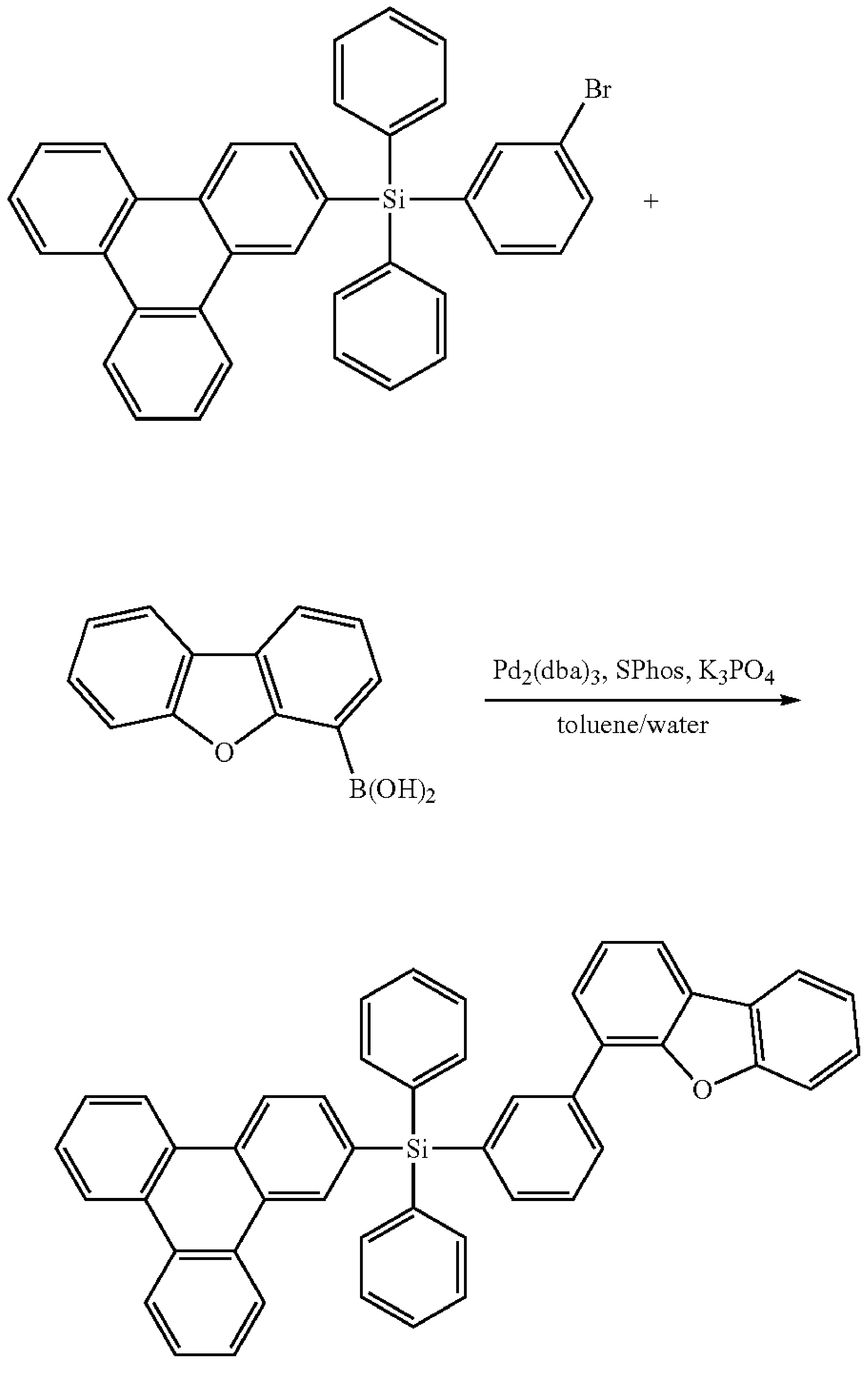


A solution of dibenzo[b,d]thiophen-4-ylboronic acid (1.573 g, 6.90 mmol), (3-bromophenyl)diphenyl(triphenylen-2-yl)silane (3, 5.30 mmol), $Pd_2(dba)_3$ (0.097 g, 0.106 mmol), SPhos (0.087 g, 0.212 mmol) and K_3PO_4 (3.38 g, 15.91 mmol) in toluene (50 mL) and water (7 mL) was stirred at 100° C. under nitrogen overnight. After cooling to room temperature, the organic phase was isolated, the aqueous phase was extracted with DCM, and the combined organic solution was dried over Na_2SO_4. Upon evaporation of the solvent, the residue was purified by column chromatography on silica gel with hexane/dichlromethane (9/1 to 8.5/1.5, v/v) as eluent to yield Compound 1 (2.4 g, 68%) as a white solid.

Synthesis of Compound 2

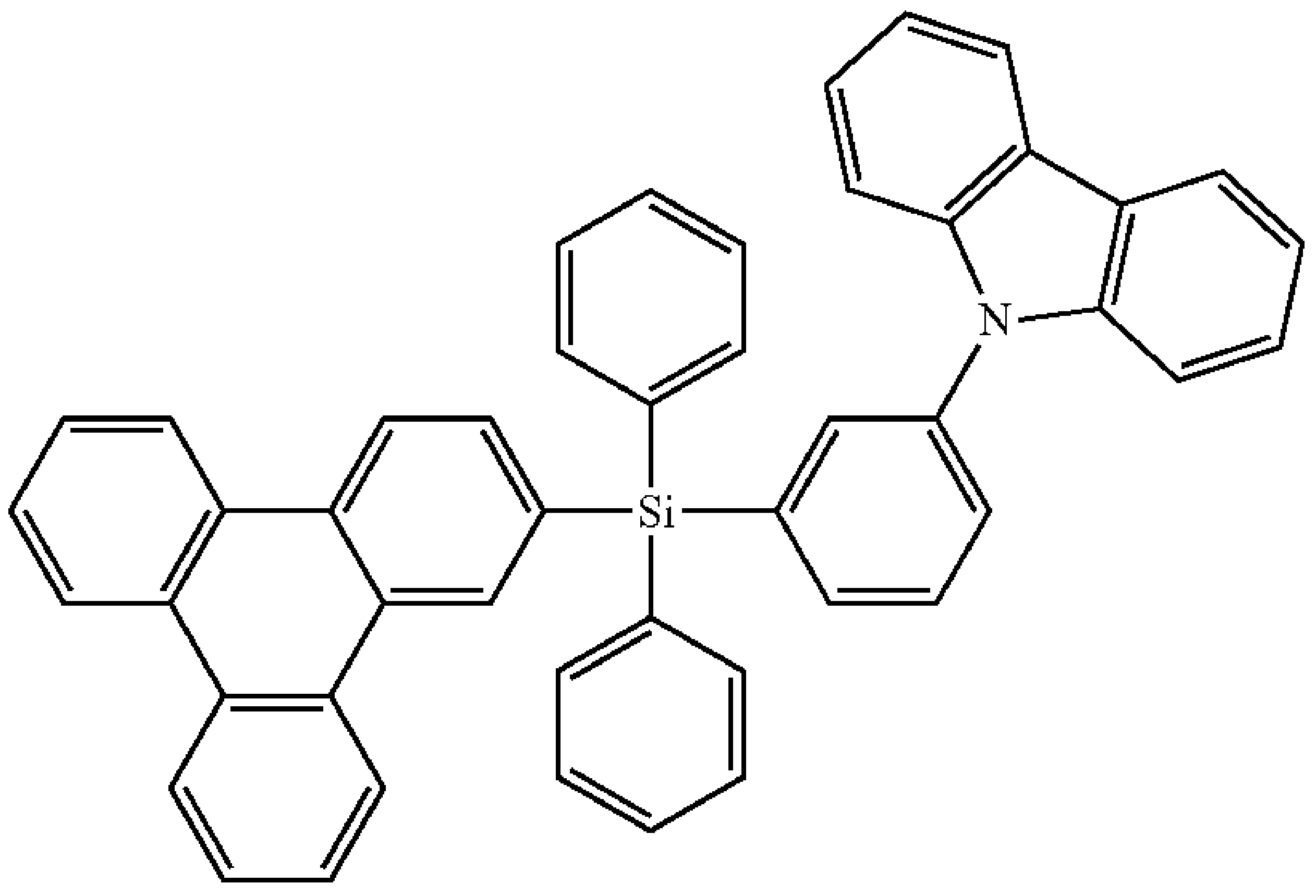
Compound 2

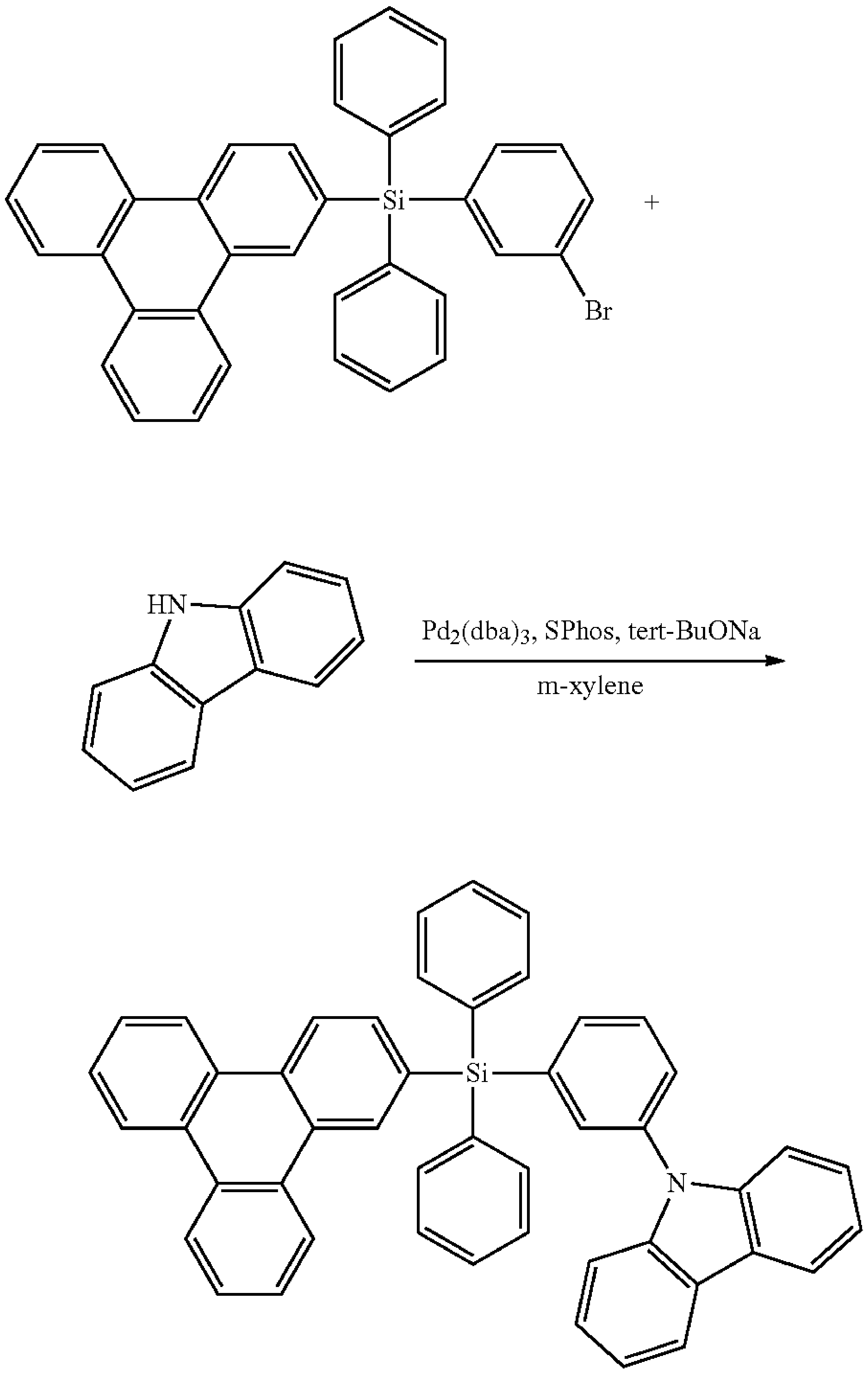




A solution of (3-bromophenyl)diphenyl(triphenylen-2-yl)silane (2.9 g, 5.13 mmol), dibenzo[b,d]furan-4-ylboronic acid (1.196 g, 5.64 mmol), $Pd_2(dba)_3$ (0.094 g, 0.10 mmol), SPhos (90 mg, 0.22 mmol) and K_3PO_4 (2.72 g, 12.82 mmol) in toluene (150 mL) and water (10 mL) was refluxed under nitrogen overnight. After evaporation off the solvent, the residue was purified by column chromatography on silica gel with hexane/DCM (4/1, v/v) as eluent to yield Compound 2 (1.5 g, 44%) as a white solid.

Synthesis of Compound 3

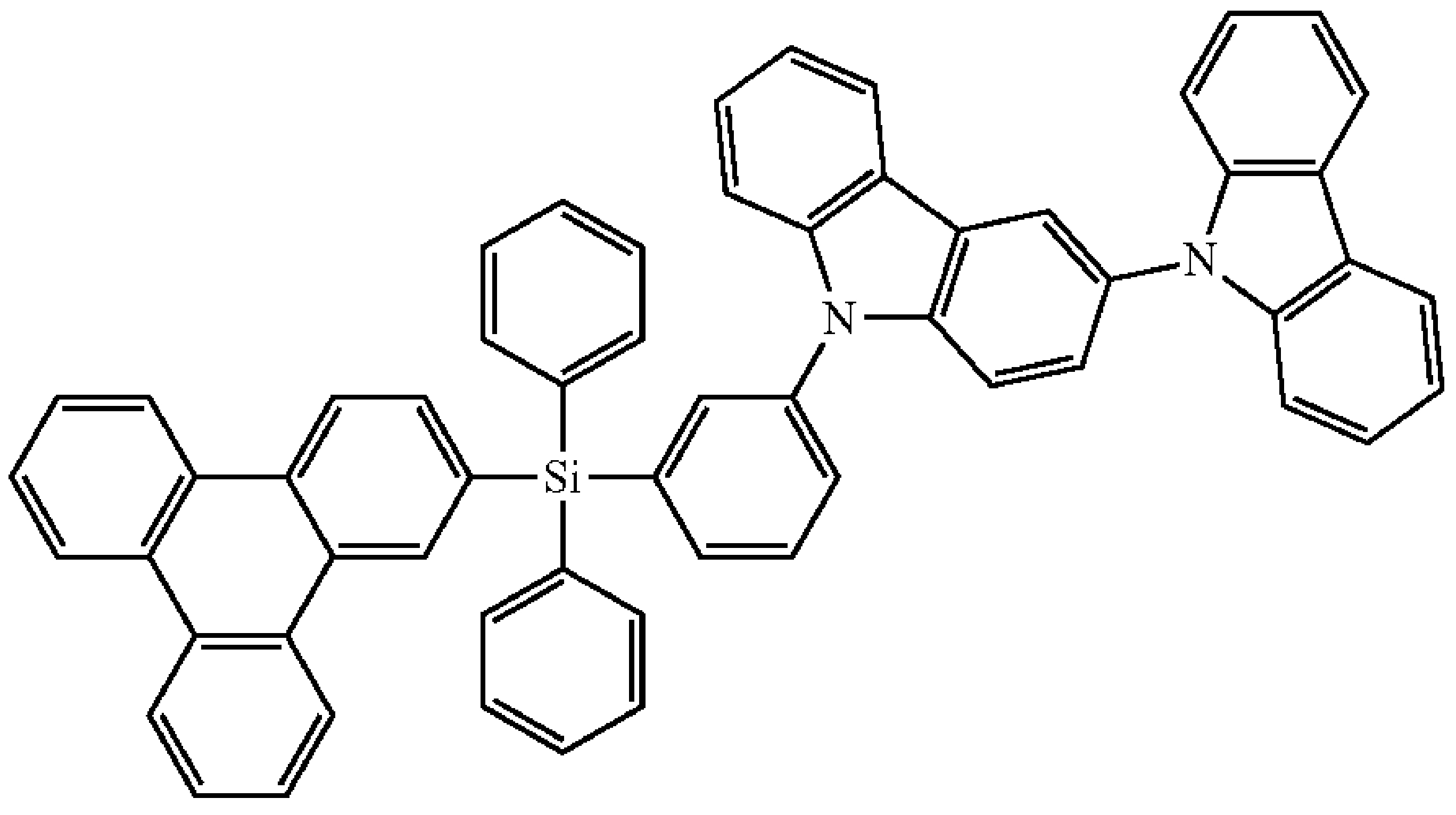


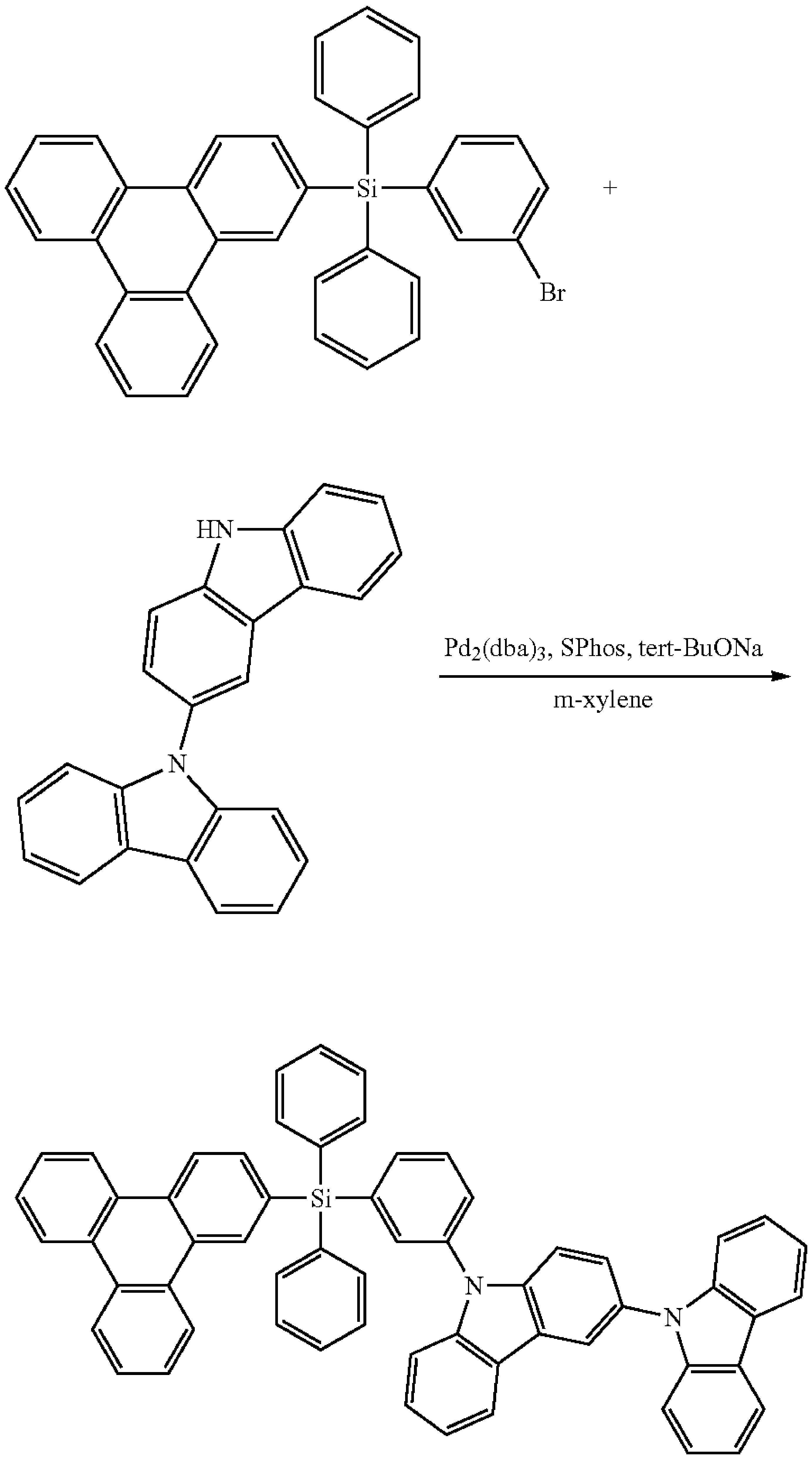


A mixture of (3-bromophenyl)diphenyl(triphenylen-2-yl) silane (3.52 g, 6.22 mmol), 9H-carbazole (1.249 g, 7.47 mmol), $Pd_2(dba)_3$ (0.114 g, 0.124 mmol), SPhos (0.102 g, 0.249 mmol), and sodium tert-butoxide (1.794 g, 18.67 mmol) in m-xylene (100 mL) was refluxed under nitrogen overnight. After cooling to room temperature, it was filtered through a plug of Celite®. The organic solution was concentrated, and the residue was purified by column chromatography on silica gel with hexane/DCM (85/15, v/v) as eluent and precipitation in methanol to yield Compound 3 (3.5 g, 86%) as a white powder.

Synthesis of Compound 4

Compound 4

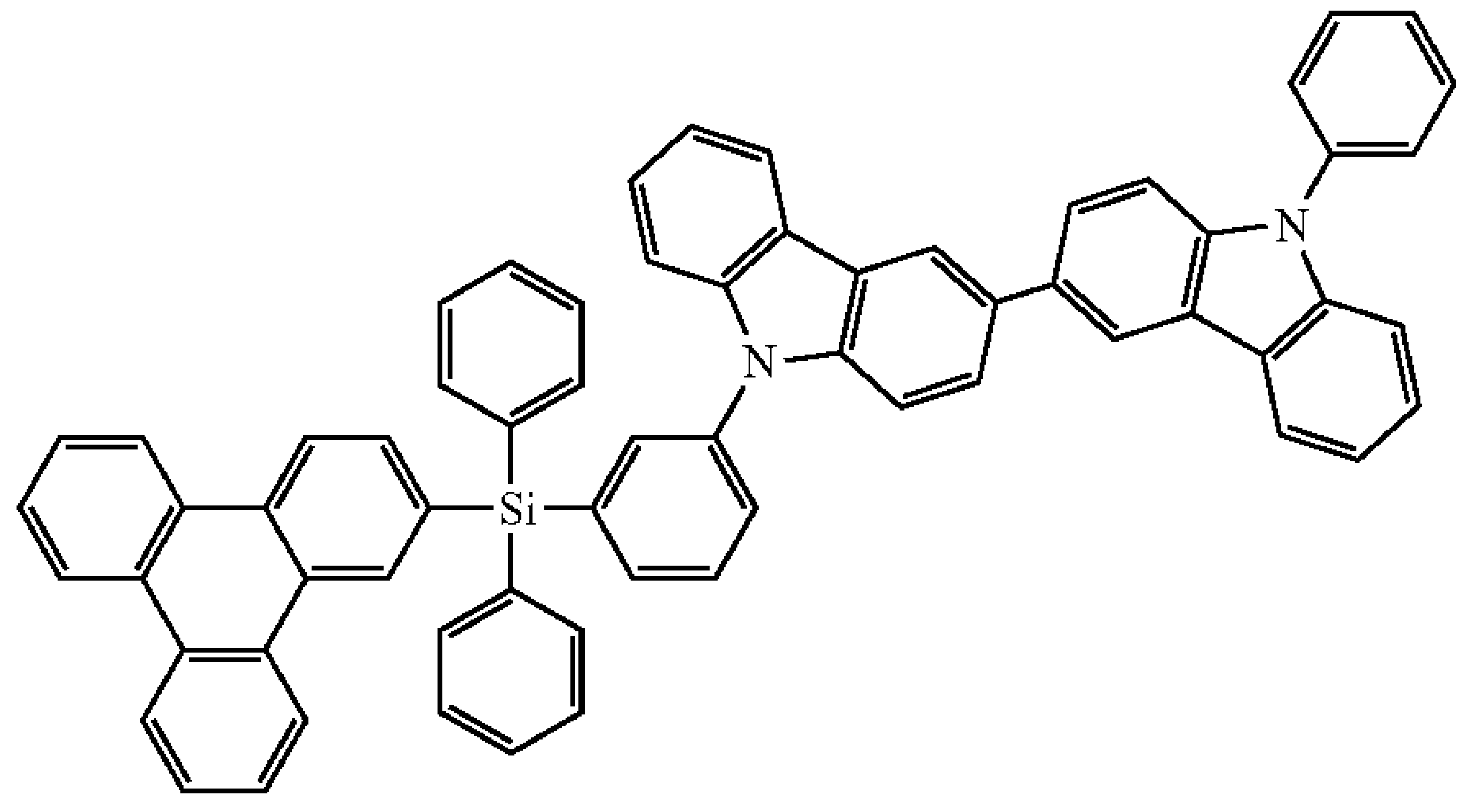


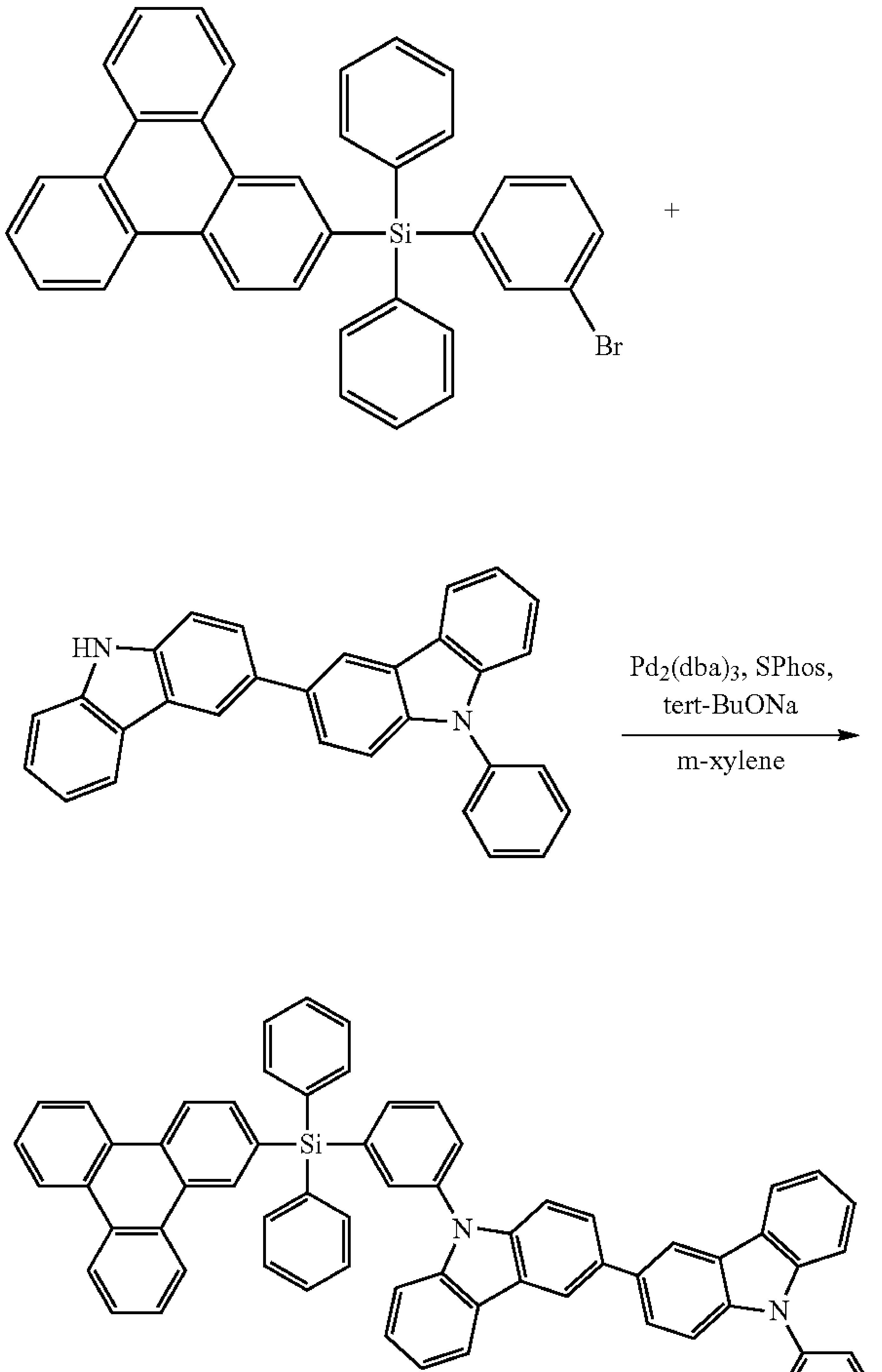


A mixture of (3-bromophenyl)diphenyl(triphenylen-2-yl) silane (3 g, 5.30 mmol), 9H-3,9'-bicarbazole (2.116 g, 6.37 mmol), $Pd_2(dba)_3$ (0.097 g, 0.106 mmol), SPhos (0.087 g, 0.212 mmol), and sodium tert-butoxide (1.529 g, 15.91 mmol) in m-xylene (100 mL) was refluxed under nitrogen at 165° C. overnight. After cooling to room temperature, it was filtered through a short plug of Celite®. Upon evaporation off the solvent, the residue was purified by column chromatography on silica gel with hexane/DCM(8/2 to 3/1, v/v) as eluent to yield Compound 4 (4.0 g, 92%) as a white solid.

Synthesis of Compound 5

Compound 5

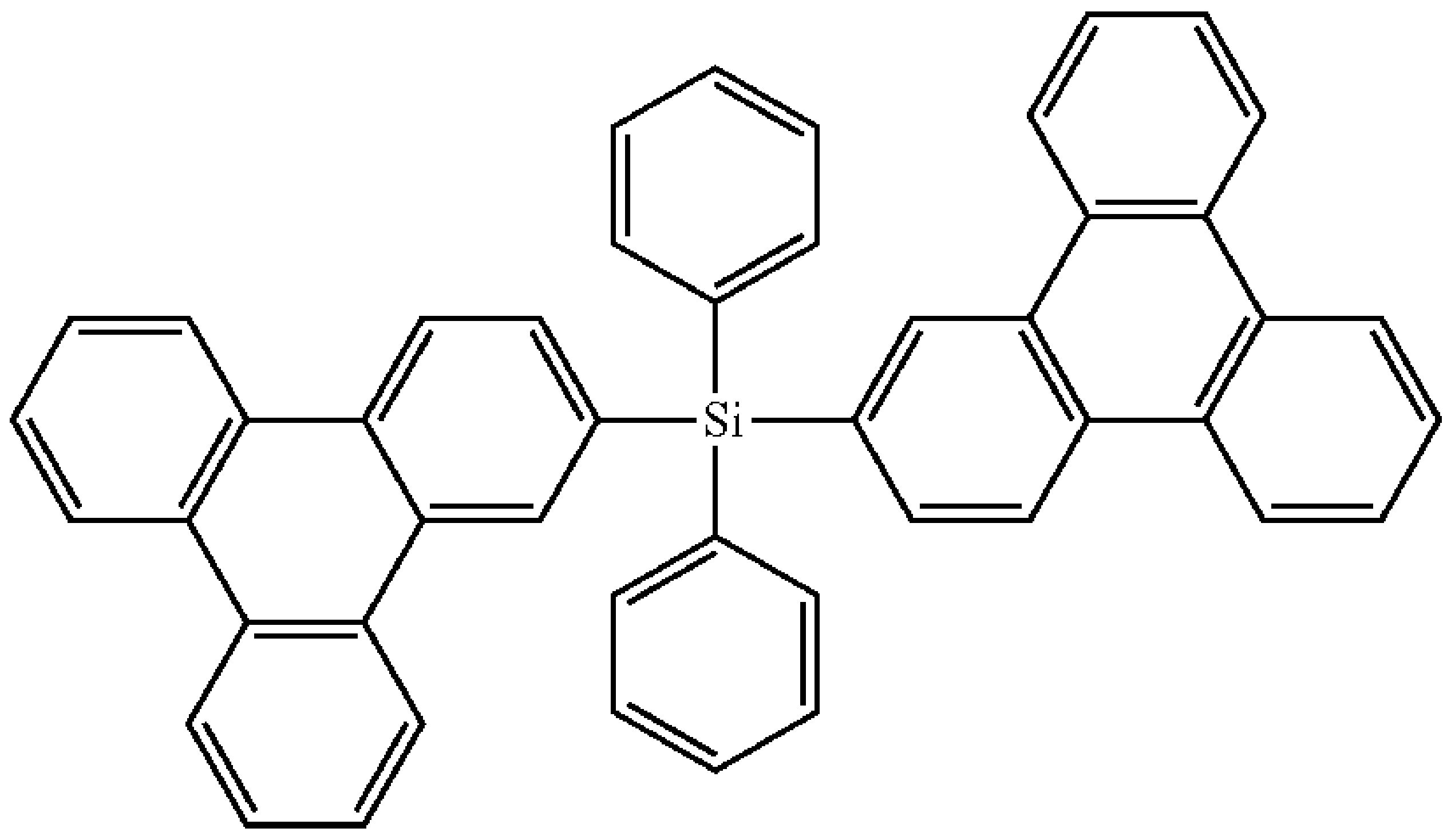


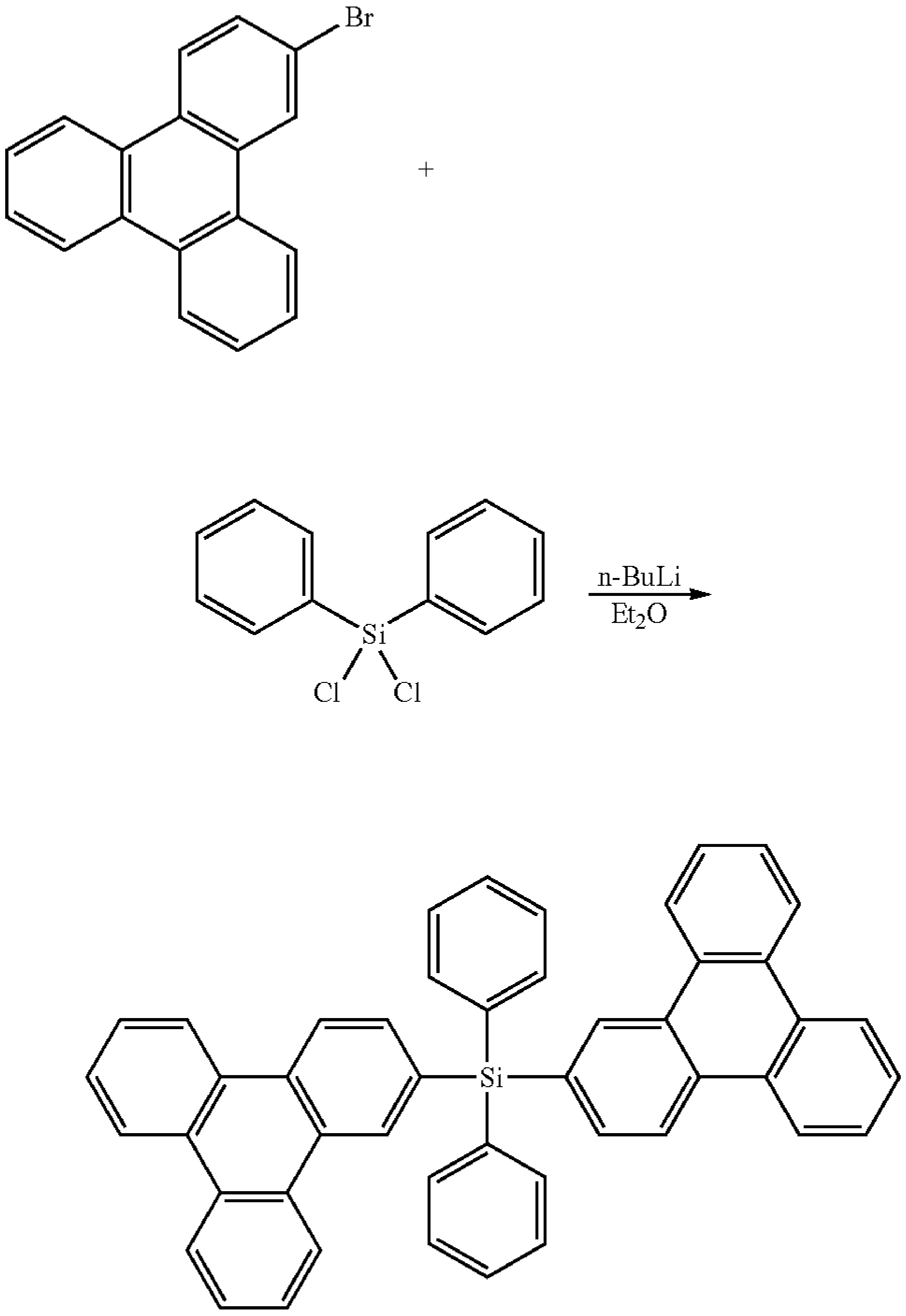


A solution of (3-bromophenyl)diphenyl(triphenylen-2-yl) silane (2.5 g, 4.42 mmol), 9-phenyl-9H,9'H-3,3'-bicarbazole (1.806 g, 4.42 mmol), $Pd_2(dba)_3$ (0.081 g, 0.088 mmol), SPhos (0.073 g, 0.177 mmol) and sodium tert-butoxide (1.274 g, 13.26 mmol) in m-xylene (80 mL) was refluxed under nitrogen overnight. After cooling to room temperature, it was passed through a short plug of Celite®. Upon evaporation off the solvent, the residue was purified by column chromatography on silica gel with hexane/DCM (4/1 to 3/2, v/v) as eluent to yield Compound 5 as a white powder.

Synthesis of Comparative Compound 1 (CC-1)

CC-1

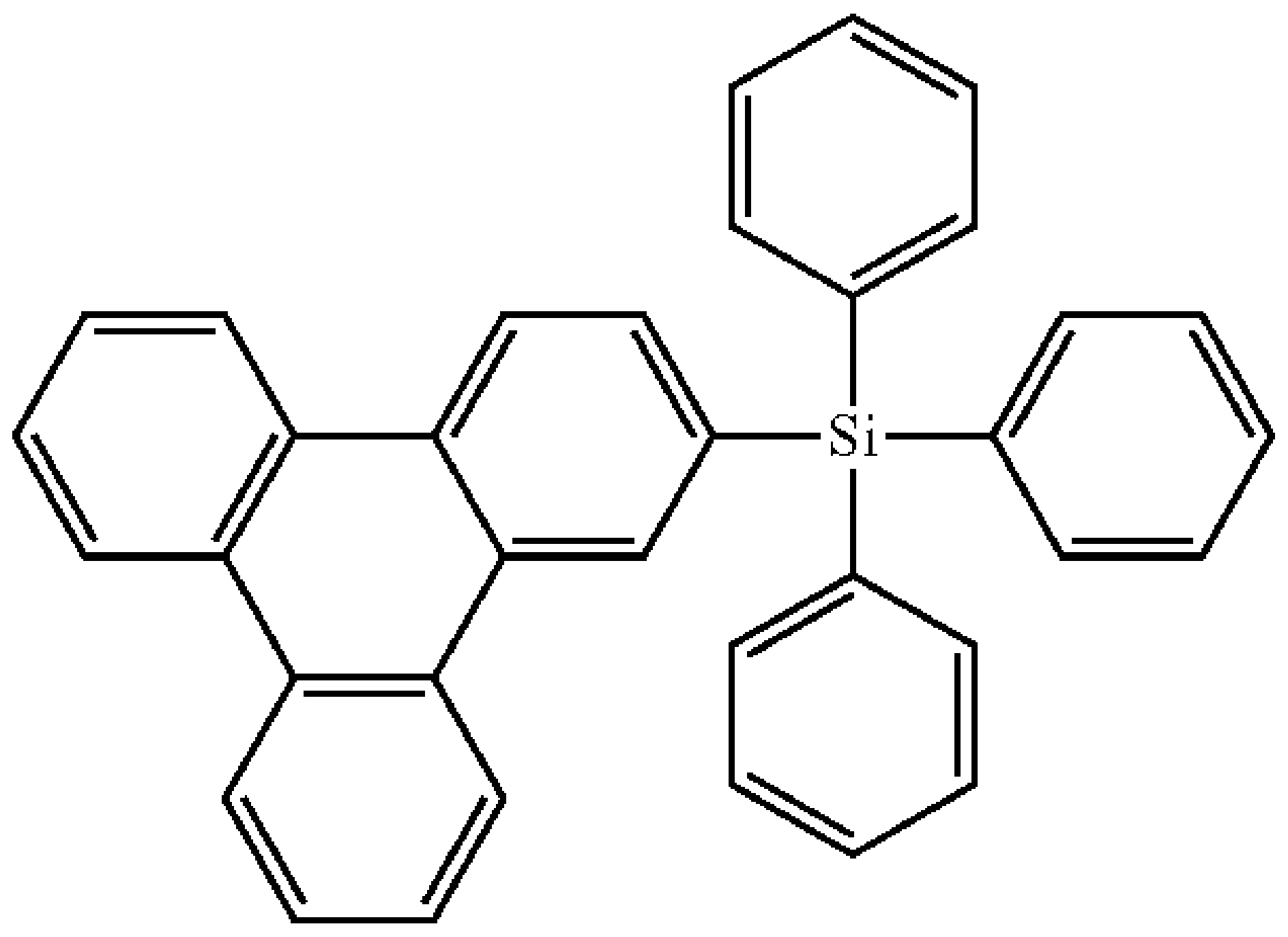


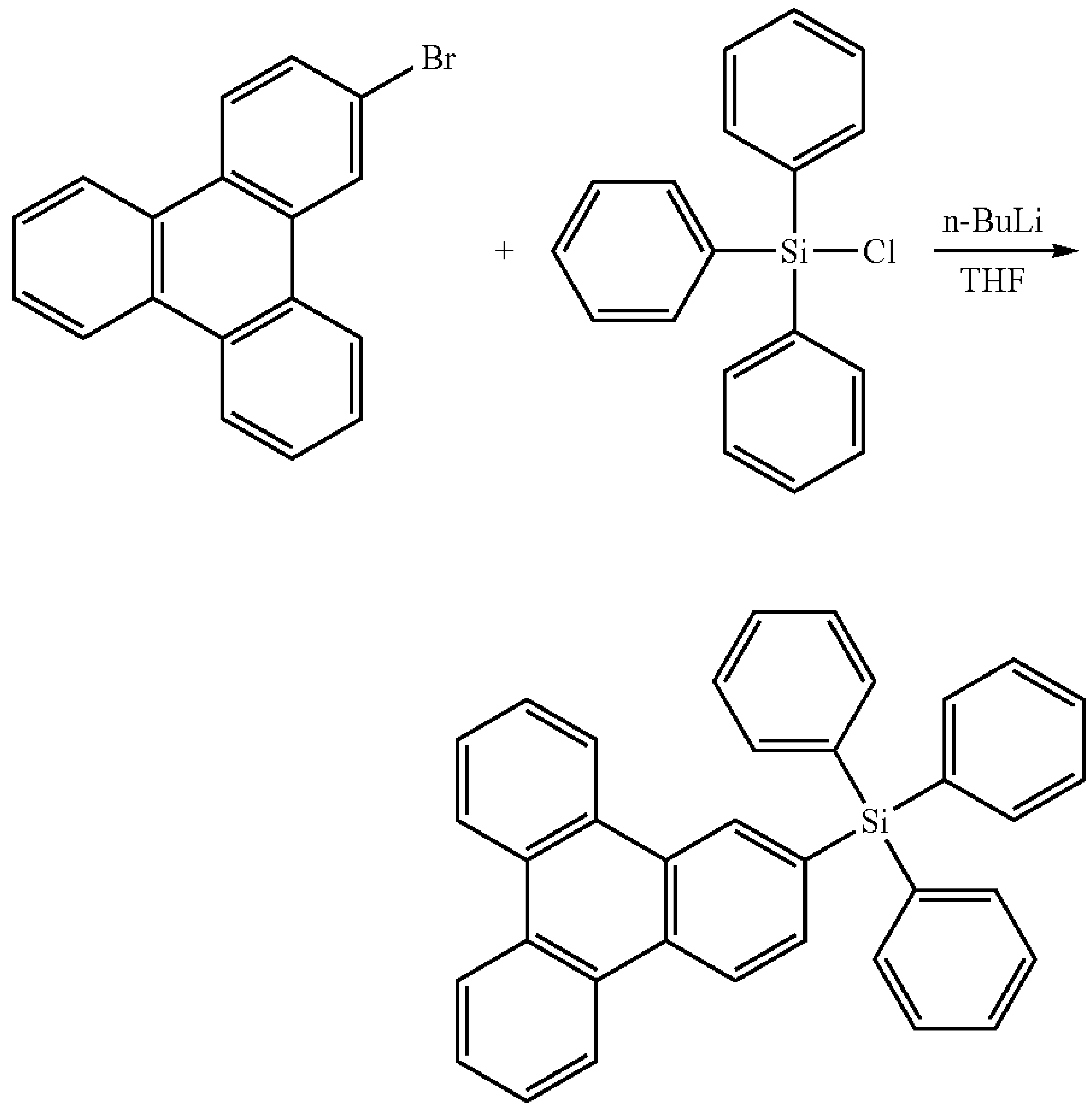


2-Bromotriphenylene (3.4 g, 11.1 mmol) was dissolved in Et_2O (100 mL) and cooled to −78° C. before n-BuLi (4.9 mL, 12.1 mmol) was added dropwise. The reaction mixture was allowed to slowly warm to −0° C. and stirred for 30 minutes before it was re-cooled to −78° C. Diphenyldichlorosilane (1.1 mL, 5.3 mmol) in 20 mL of Et_2O was added dropwise to the reaction mixture. After slowly warming to room temperature overnight the thick mixture was refluxed for 3 h. After cooling to room temperature, 300 mL of water was added with rapid stirring and the precipitate was filtered from the biphasic mixture, washing with Et_2O. The solid was dissolved in DCM and filtered through a plug of silica gel on a frit. Removal of the solvent yielded CC-1 (2.4 g, 72%) as a white solid.

Synthesis of Comparative Compound 2 (CC-2)

CC-2





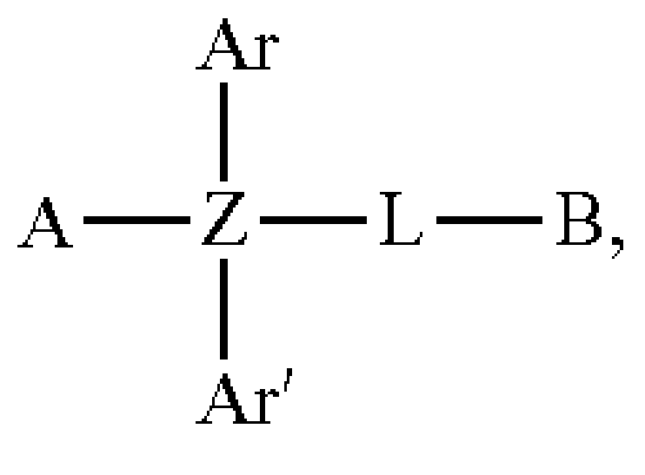
2-Bromotriphenylene (5.5 g, 14.3 mmol) was dissolved in THF (50 mL) and cooled to −78° C. before n-BuLi (5.7 mL, 14.3 mmol) was added dropwise. The reaction mixture was allowed to slowly warm to −30° C. before it was recooled to −78° C. Chlorotriphenylsilane (3.8 g, 13.0 mmol) was dissolved in 20 mL of THF and added dropwise to the reaction mixture which was subsequently allowed to slowly warm to room temperature overnight and further heated to 40° C. for 2 h. After cooling to room temperature, the reaction was quenched with MeOH and NH_4Cl (aq.), extracted three times with EtOAc (50 mL), dried and rotovapped to give 7.8 g of a yellow solid. The crude material was chromatographed on silica hexane/DCM (9/1, v/v) as eluent. Recrystallization from DCM/hexane gave CC-2 (5.5 g, 87%) as a white crystalline solid.

It is understood that the various embodiments described herein are by way of example only, and are not intended to limit the scope of the invention. For example, many of the materials and structures described herein may be substituted with other materials and structures without deviating from the spirit of the invention. The present invention as claimed may therefore include variations from the particular examples and preferred embodiments described herein, as will be apparent to one of skill in the art. It is understood that various theories as to why the invention works are not intended to be limiting.

The invention claimed is:

1. A compound having formula:

Formula I



$$A—\underset{\displaystyle Ar'}{\overset{\displaystyle Ar}{Z}}—L—B,$$

wherein Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, naphthalene, dibenzothiophene and dibenzofuran, which are optionally further substituted;

Z is selected from Si and Ge;

L is a single bond or comprises an aryl or heteroaryl group having from 5-20 carbon atoms, which is optionally further substituted;

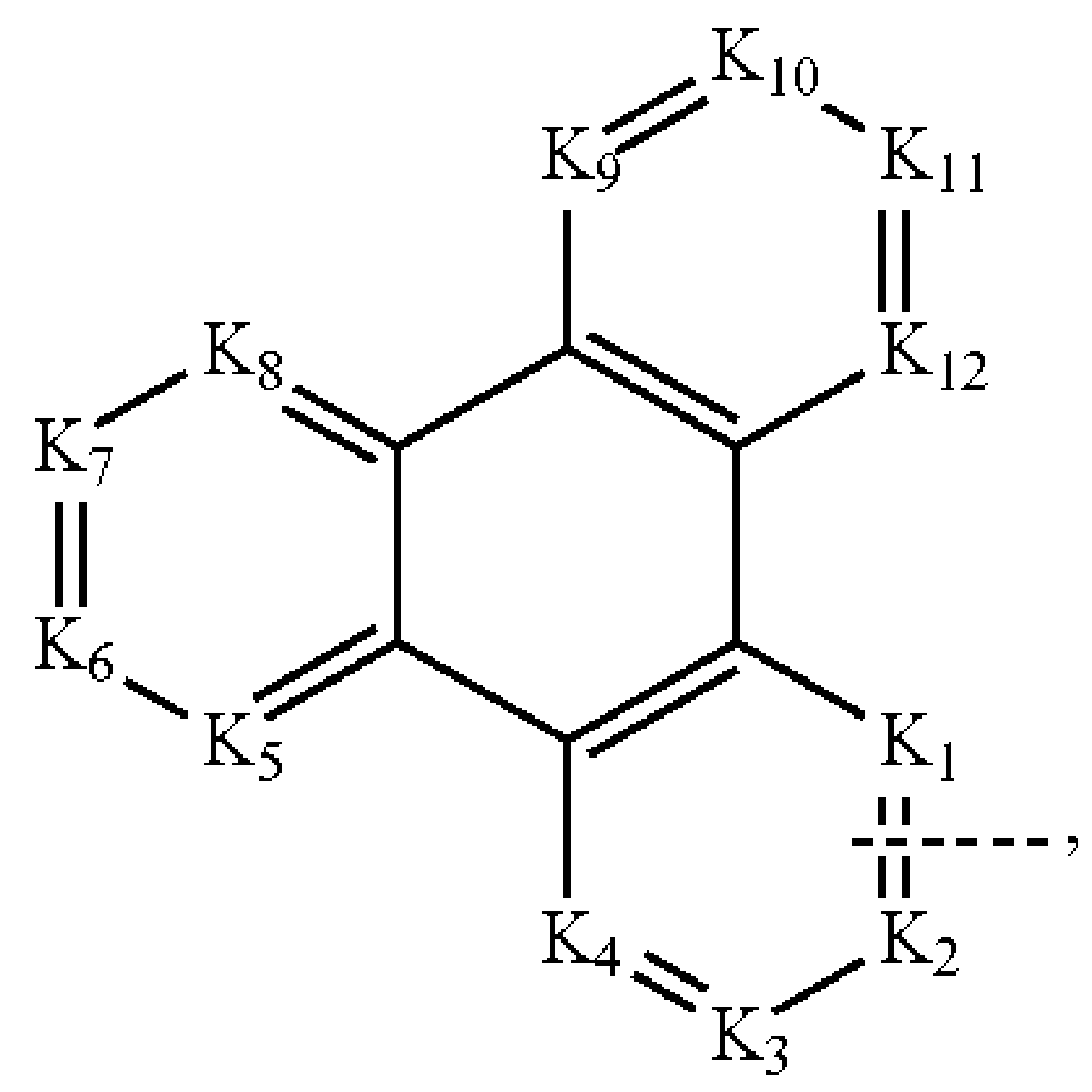
A is a group directly bonded to Z and is selected from the group consisting of triphenylene, tetraphenylene, pyrene, naphthalene, fluoranthene, chrysene, phenanthrene, azatriphenylene, azatetraphenylene, azapyrene, azanaphthalene, azafluoranthene, azachrysene, azaphenanthrene, and combinations thereof, which are optionally further substituted with one or more groups selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof;

B is a group selected from the group consisting of carbazole, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene, azadibenzoselenophene, and combinations thereof, which are optionally further substituted with one or more groups selected from hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

wherein the substitution is optionally fused to the carbazole, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene or aza-dibenzoselenophene group

wherein when B is carbazole, the carbazole group is connected to L through a ring carbon.

2. The compound of claim 1, wherein A is

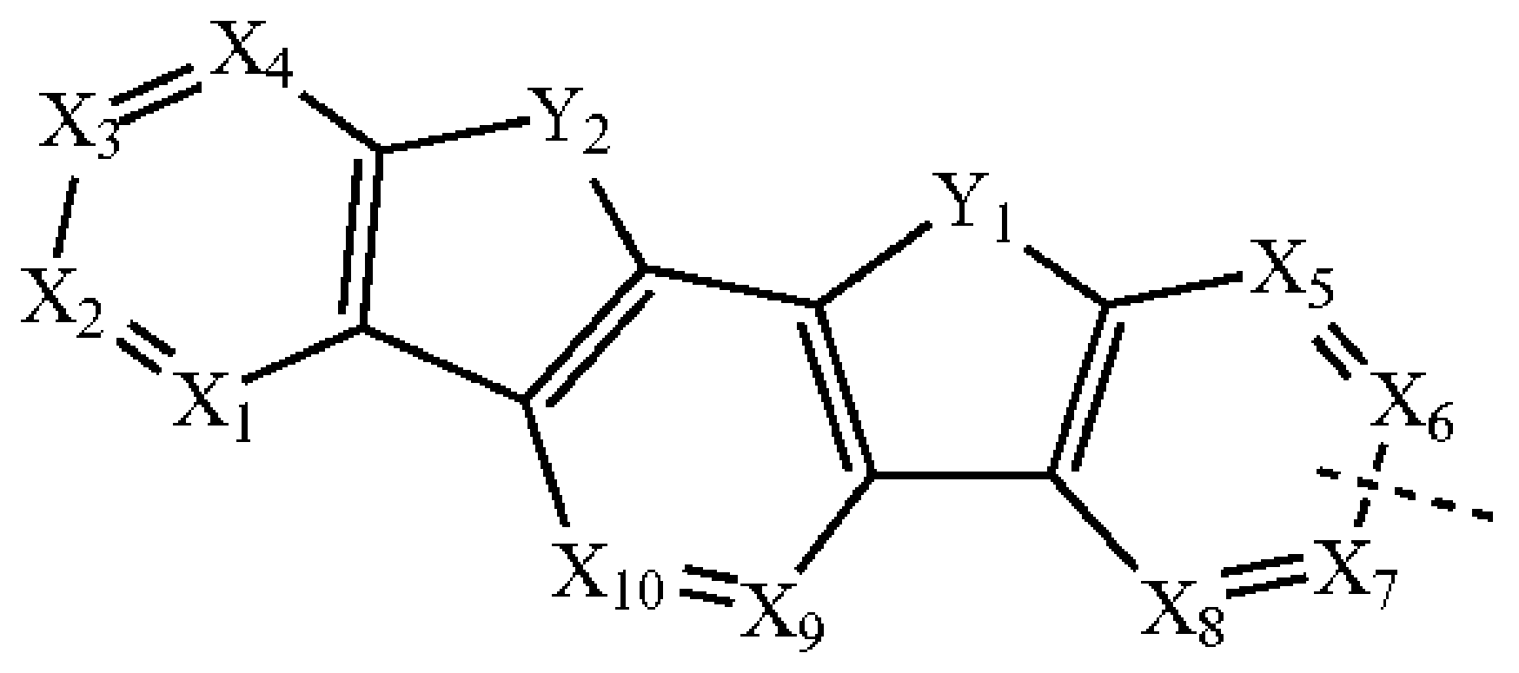


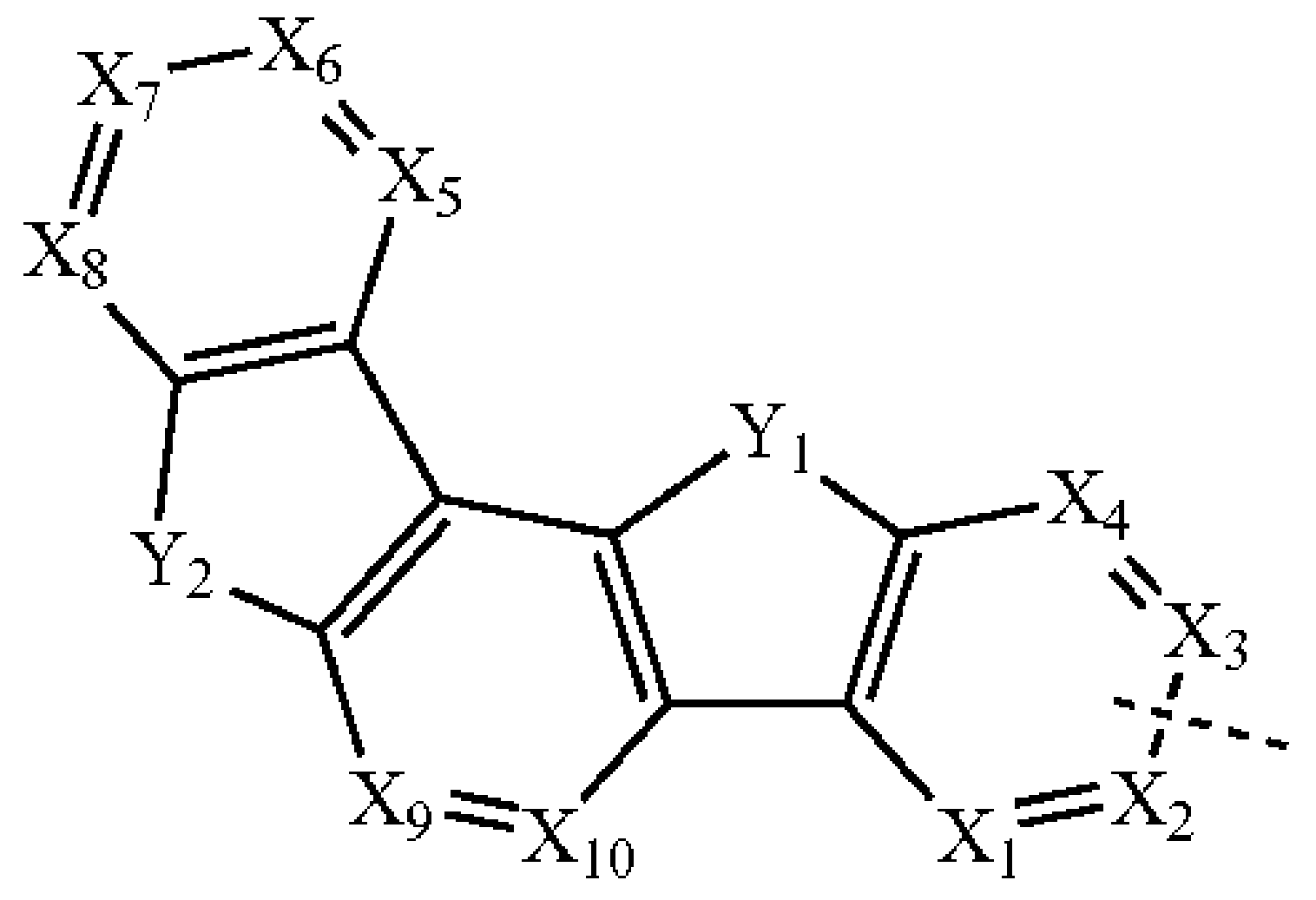
wherein K_1 to K_{12} are independently selected from N and C—R'; and

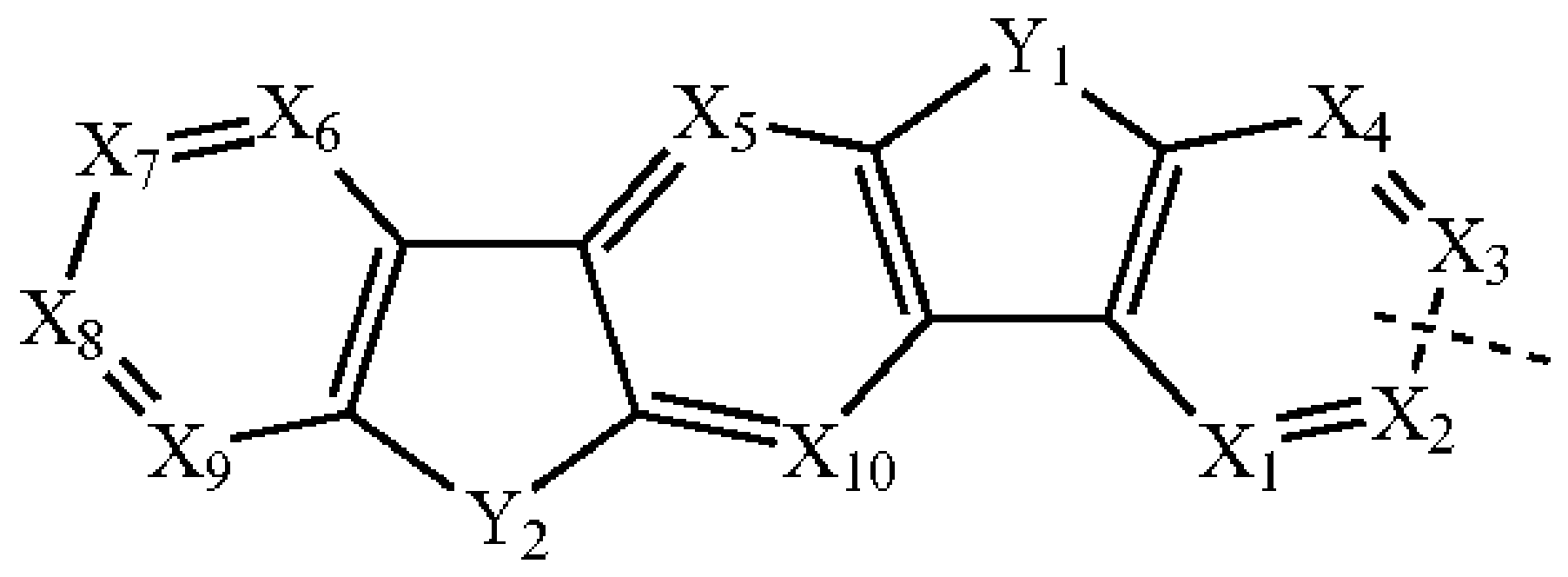
wherein R' is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof,

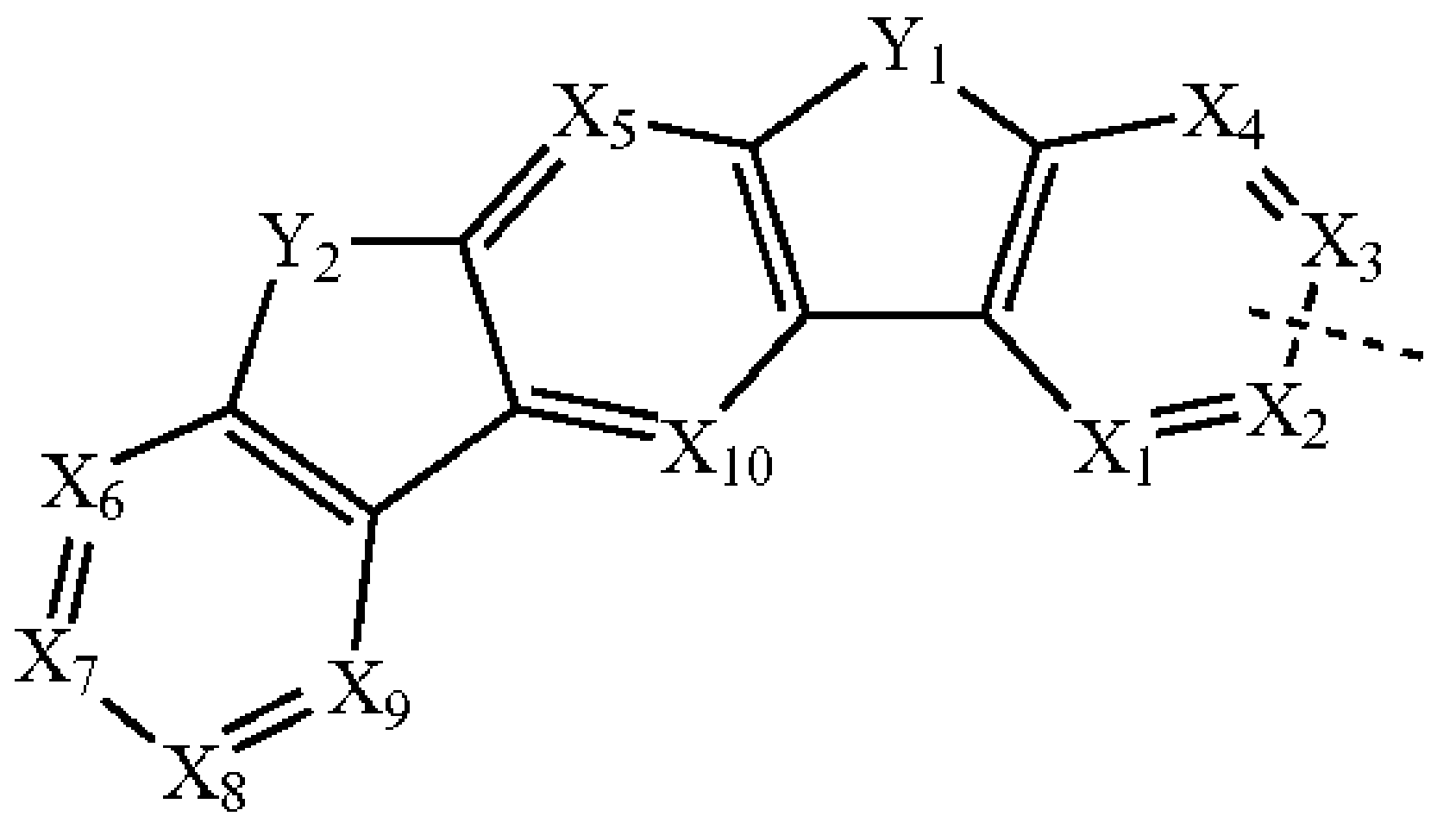
wherein R' does not exist on one of K_1 to K_4 when said one of K_1 to K_4 is bonded to Z is C.

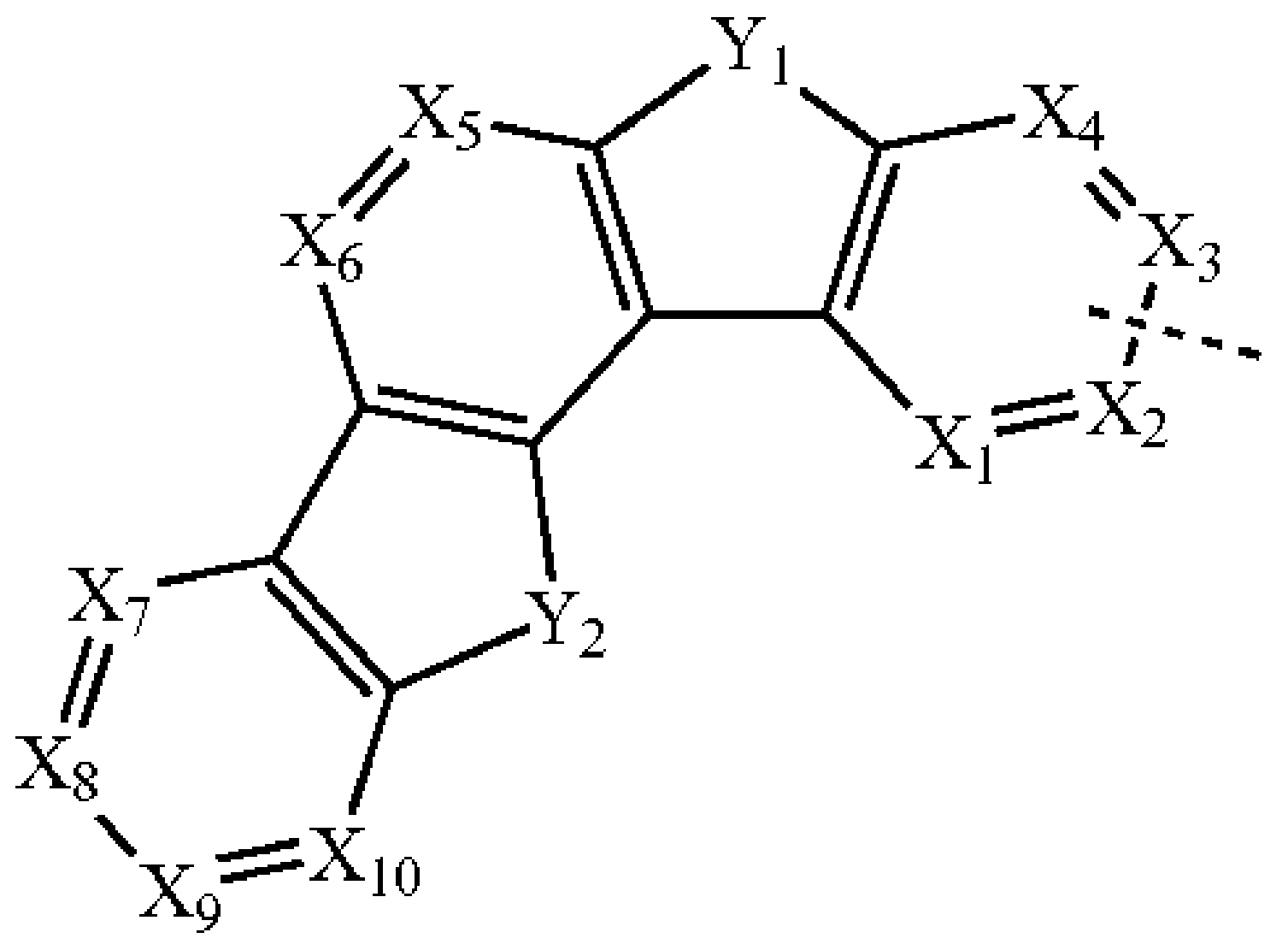
3. The compound of claim **1**, wherein B is selected from the group consisting of:

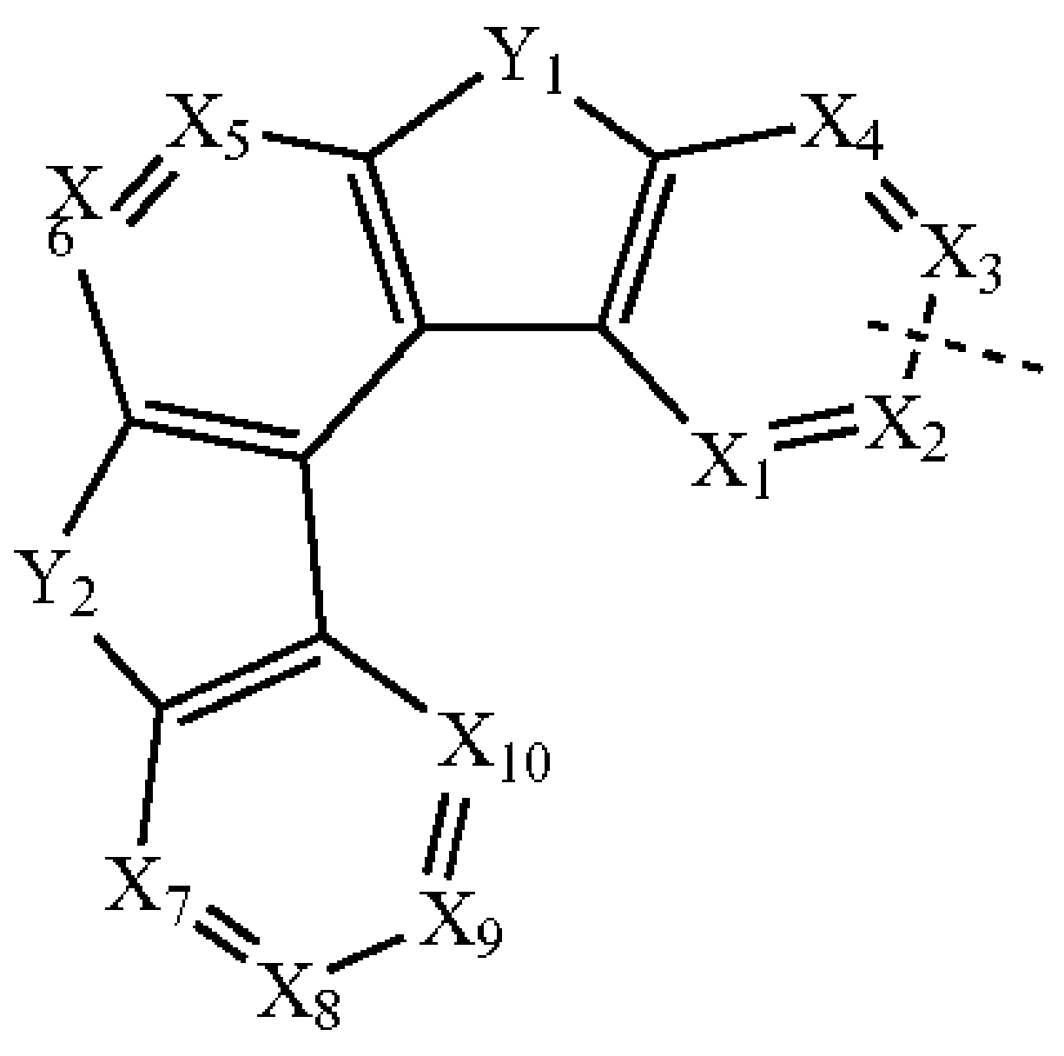


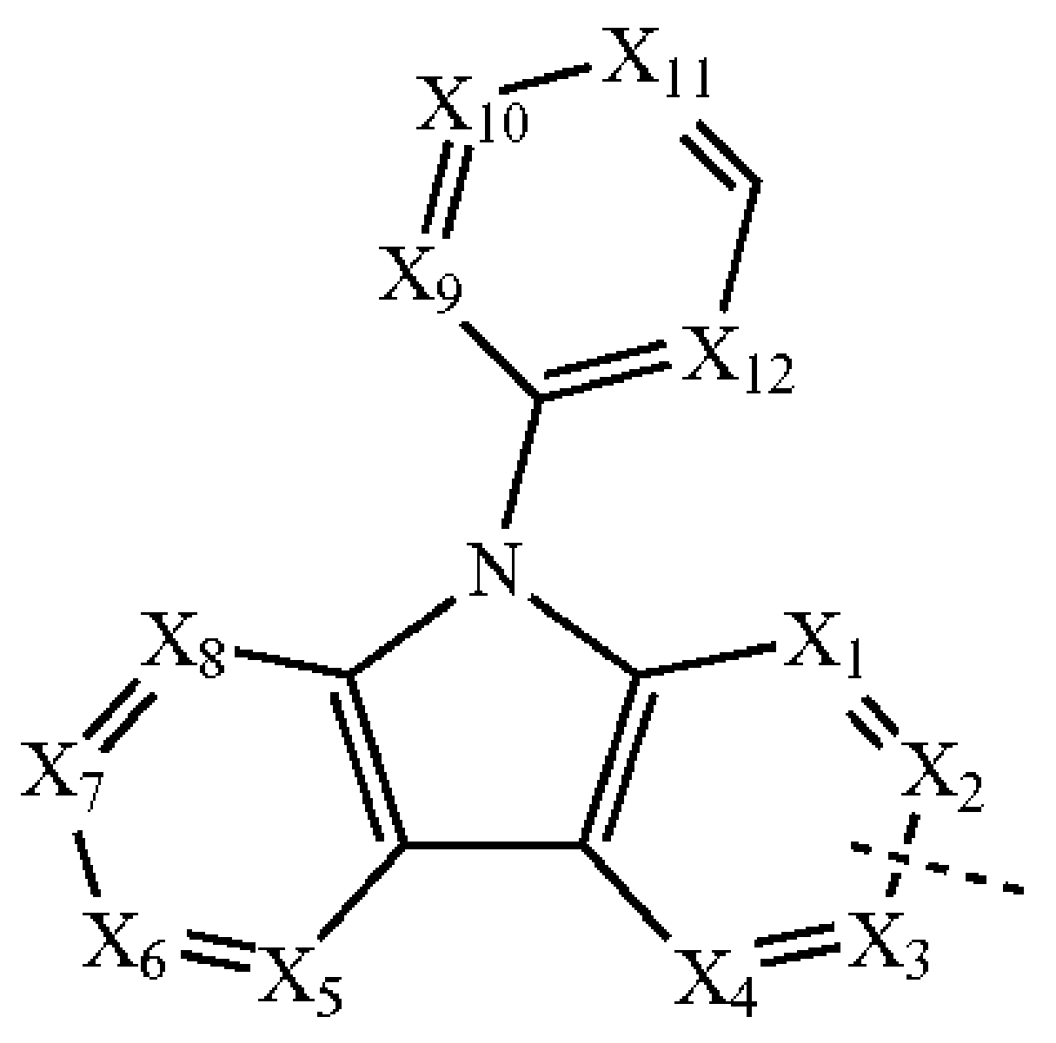












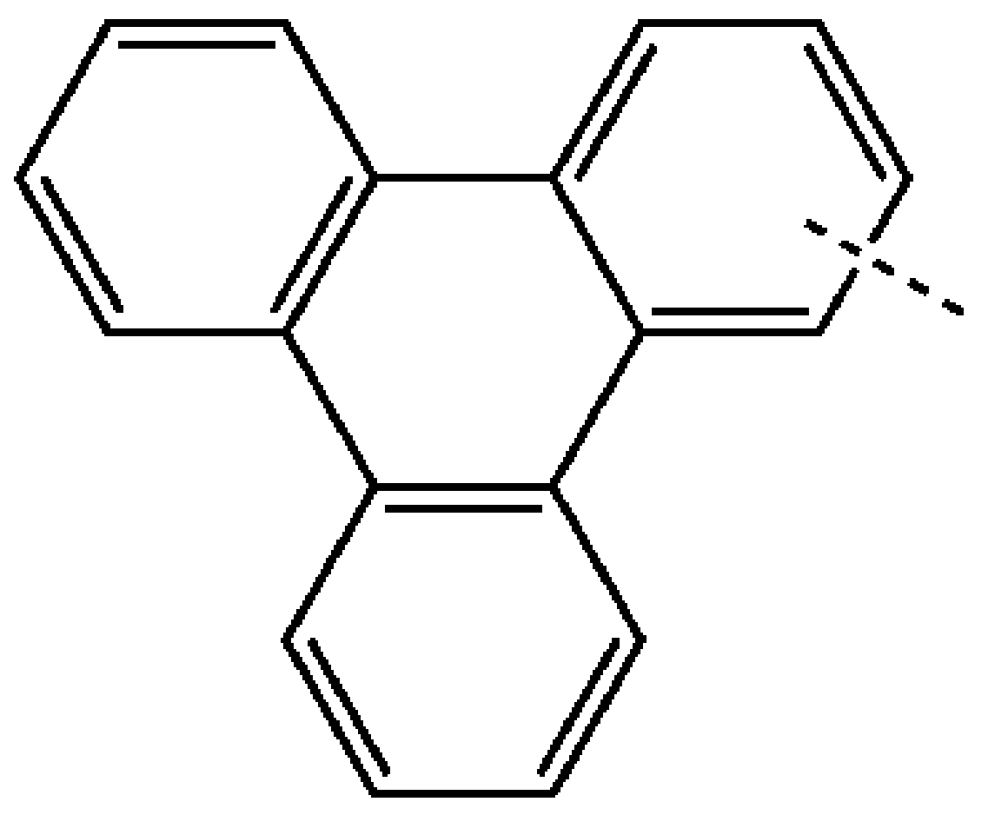
wherein X_1-X_{15} are independently selected from the group consisting of N and C—R",

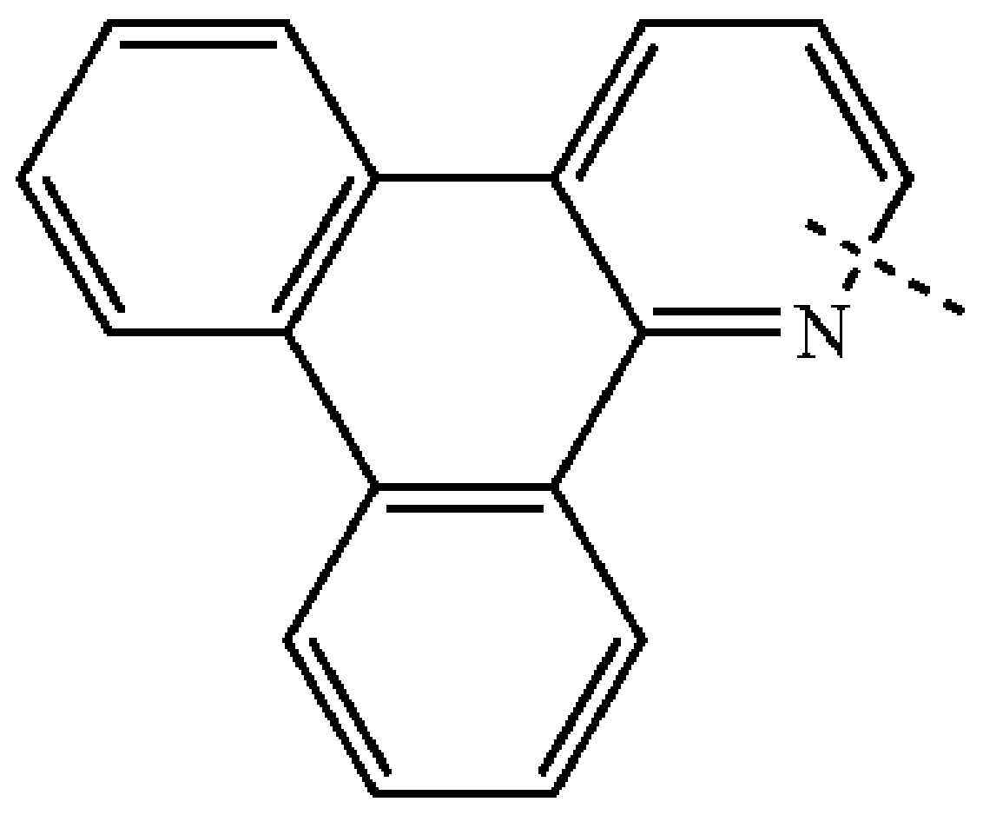
wherein R" is selected from a group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof,

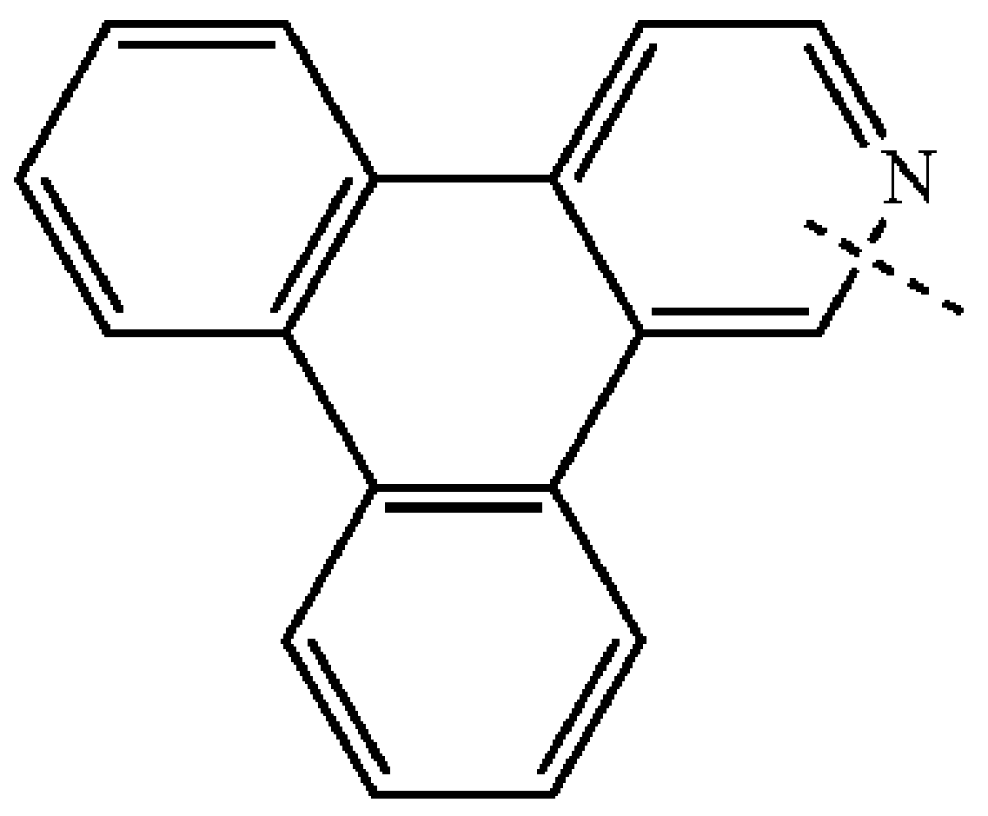
wherein R" does not exist on one of X_1 to X_8 when said one of X_1 to X_8 that is bonded to L is C; and

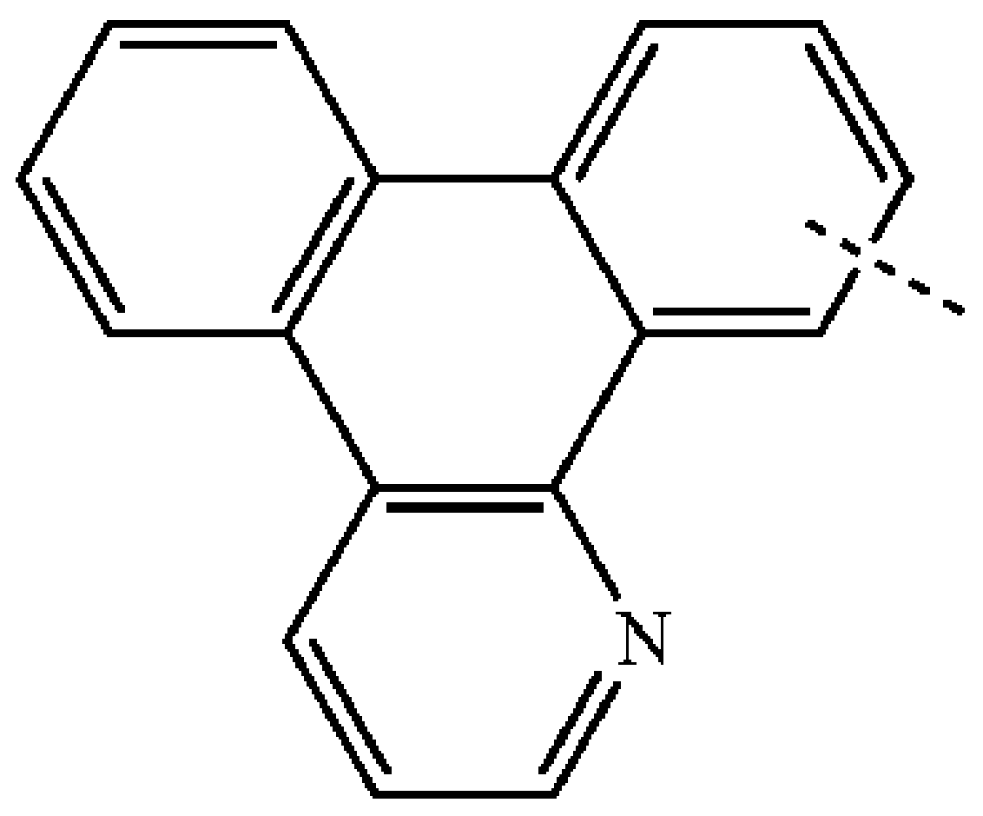
wherein Y_1 and Y_2 are independently selected from the group consisting of O, S, and Se.

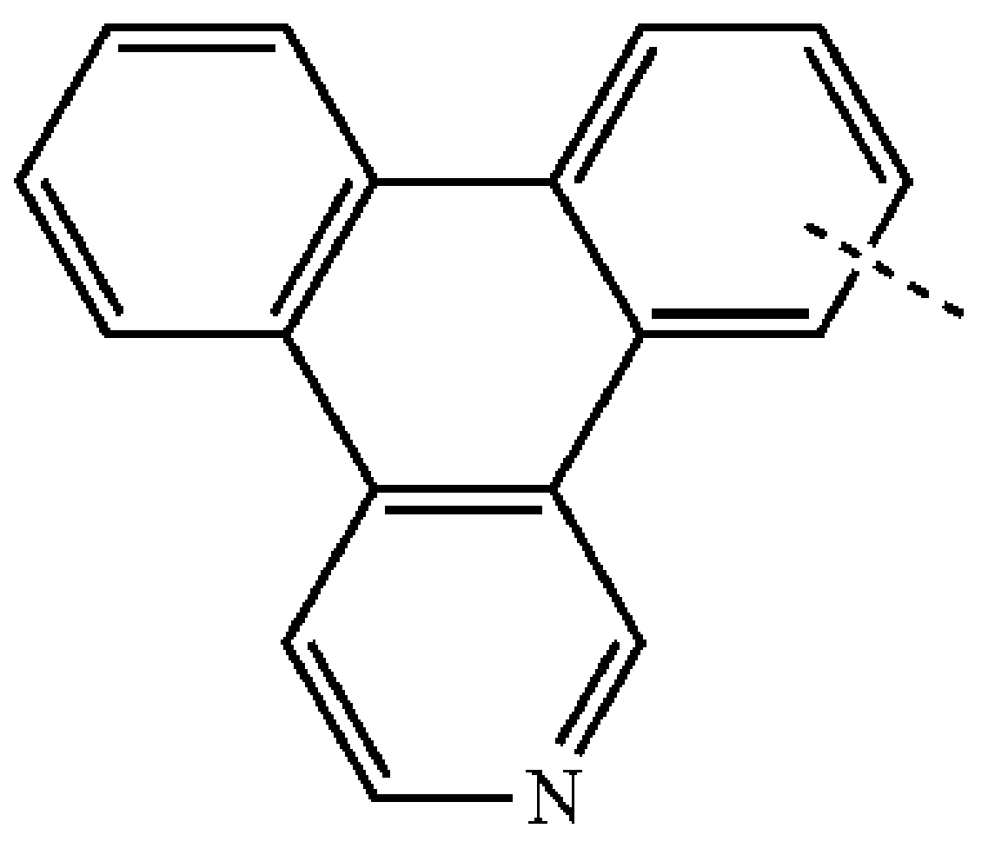
4. The compound of claim **1**, wherein A is selected from the group consisting of:

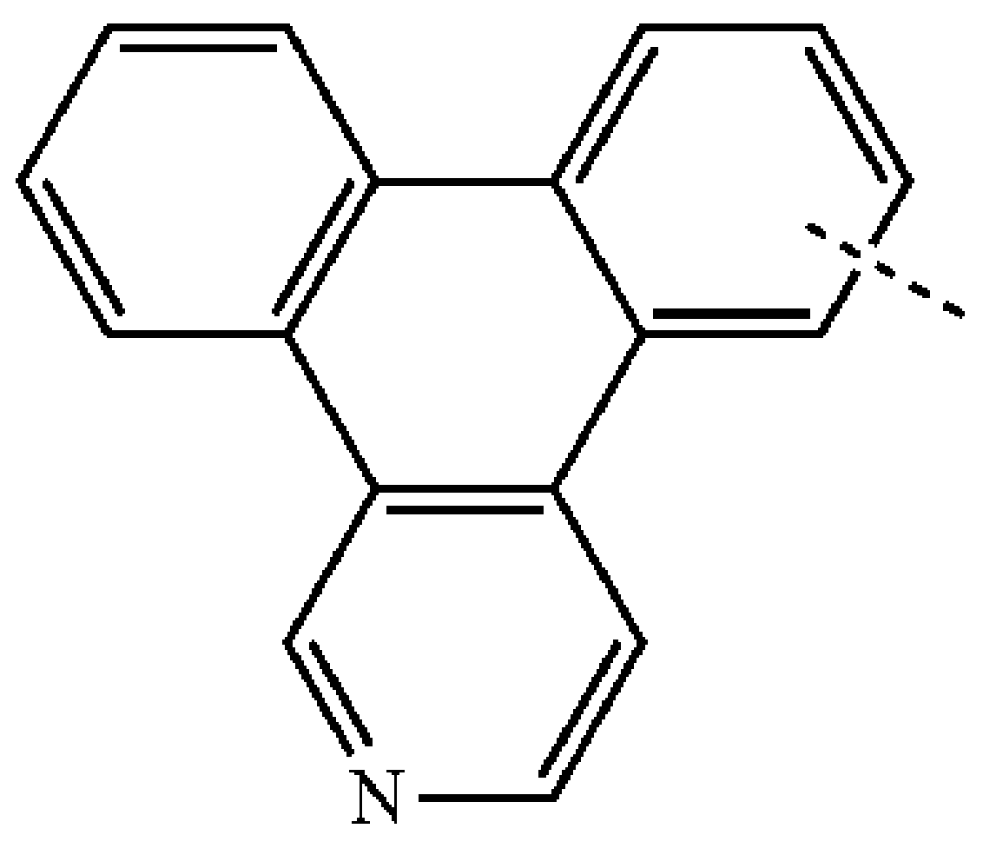


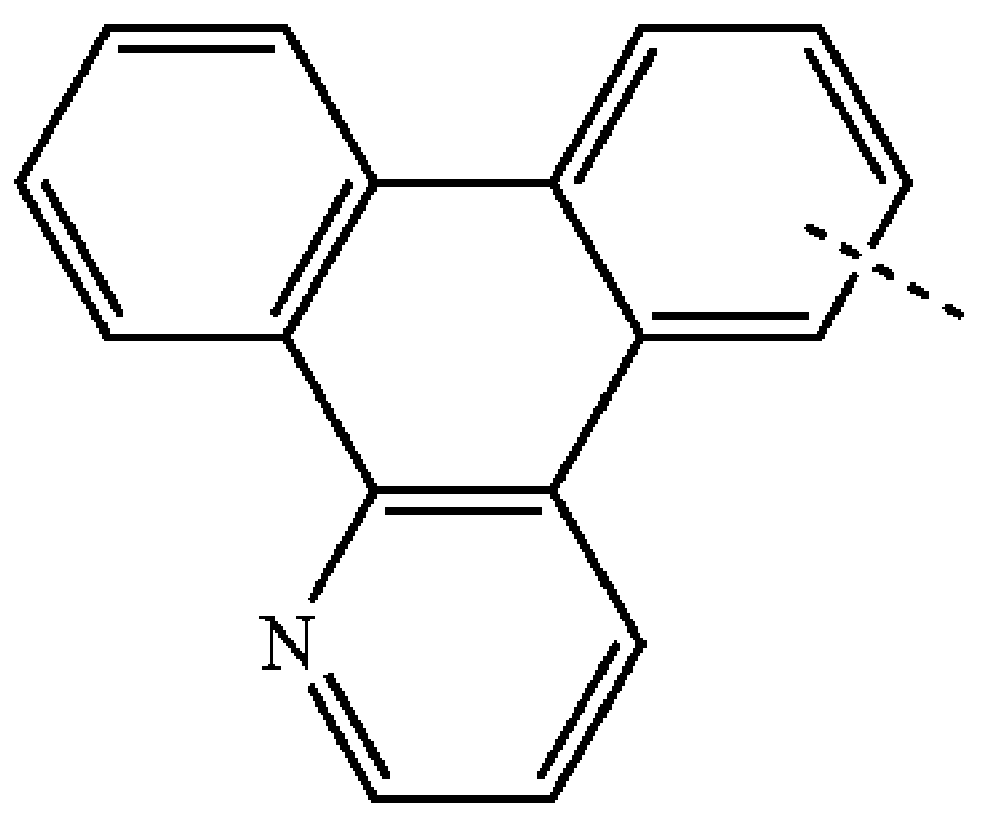


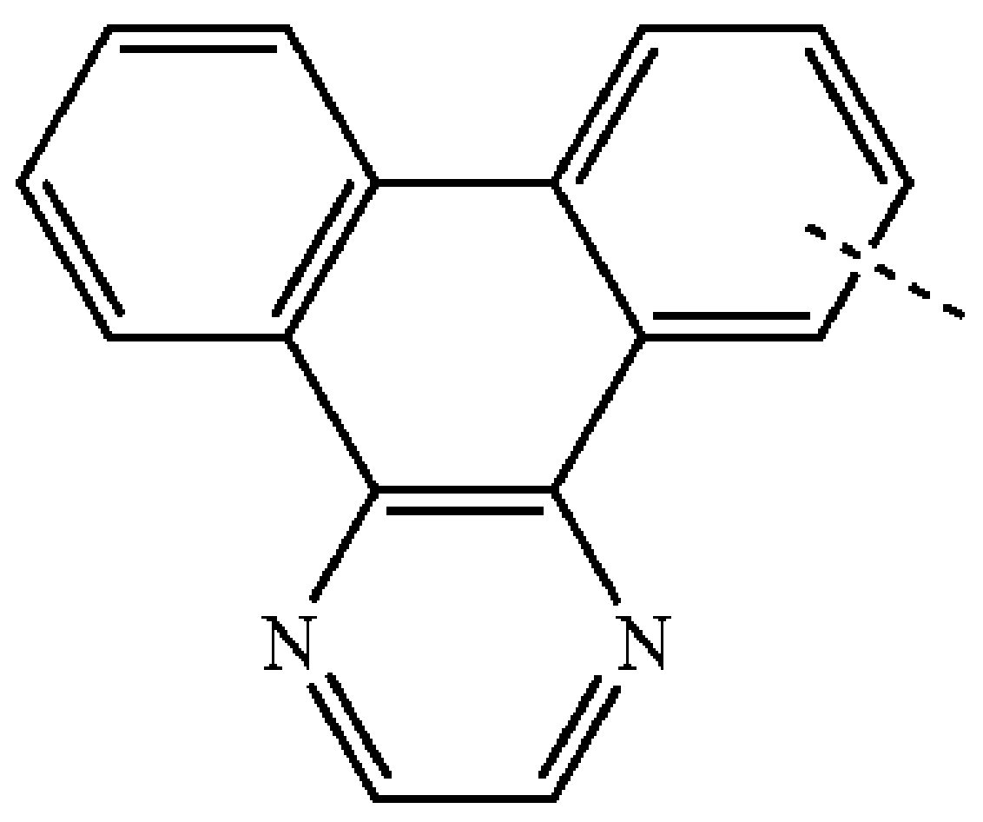


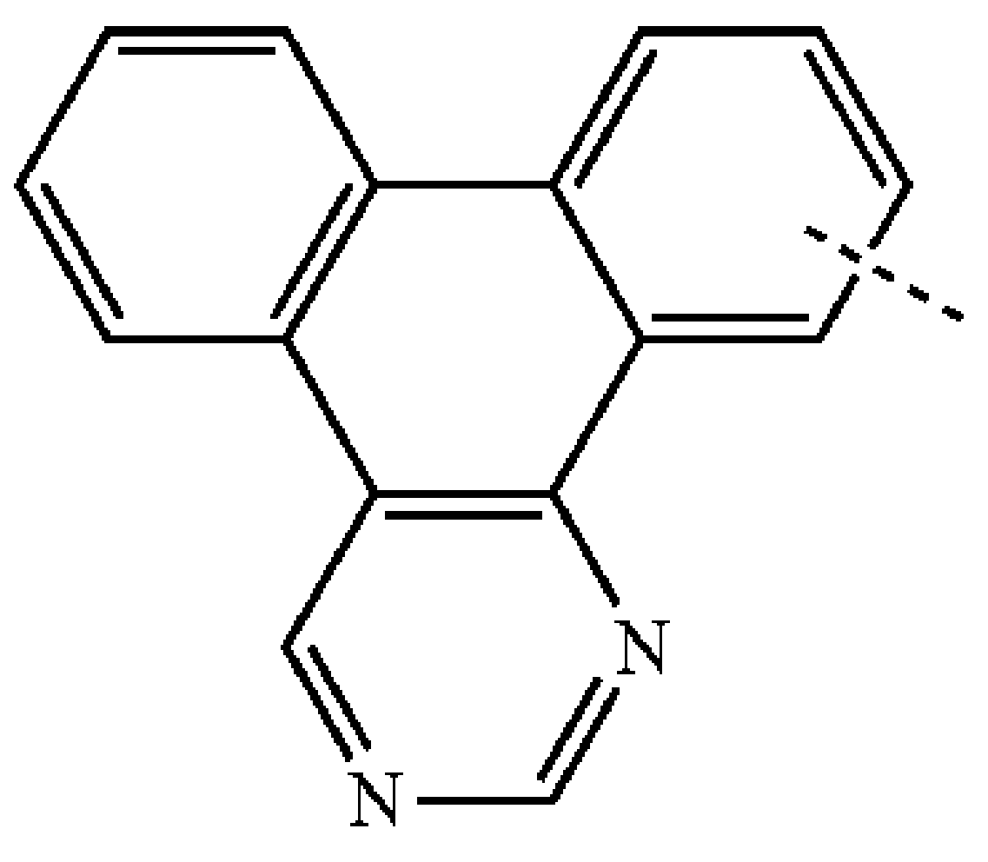


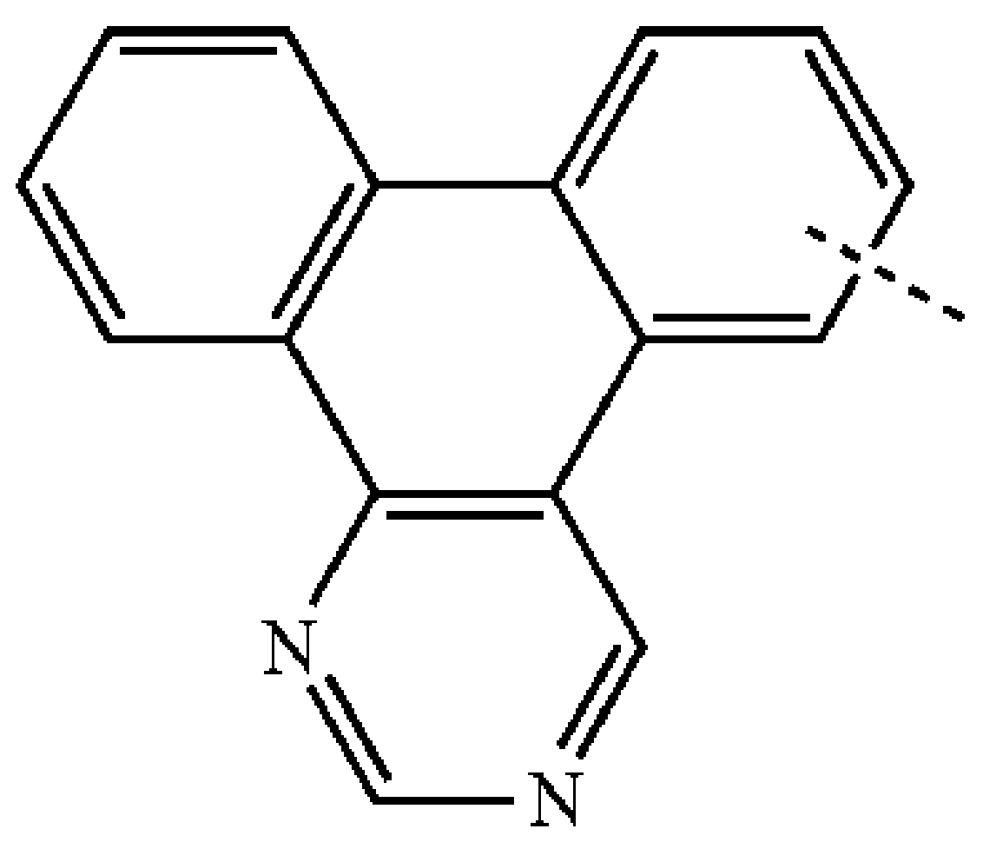


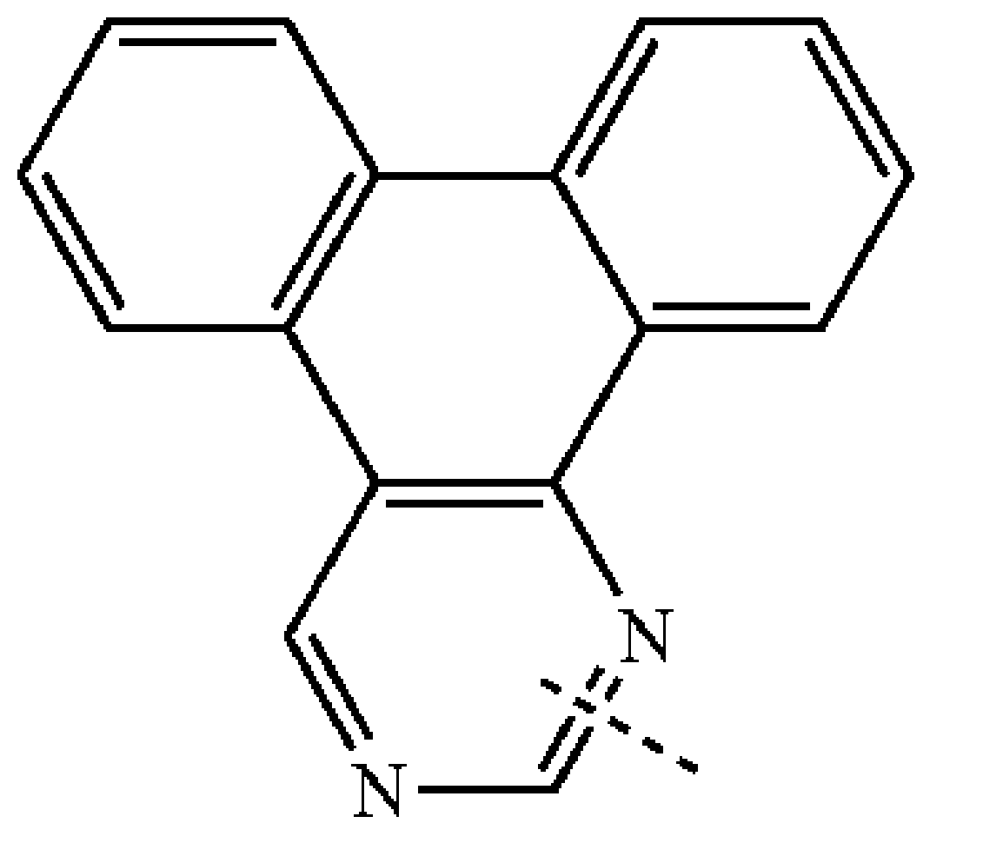


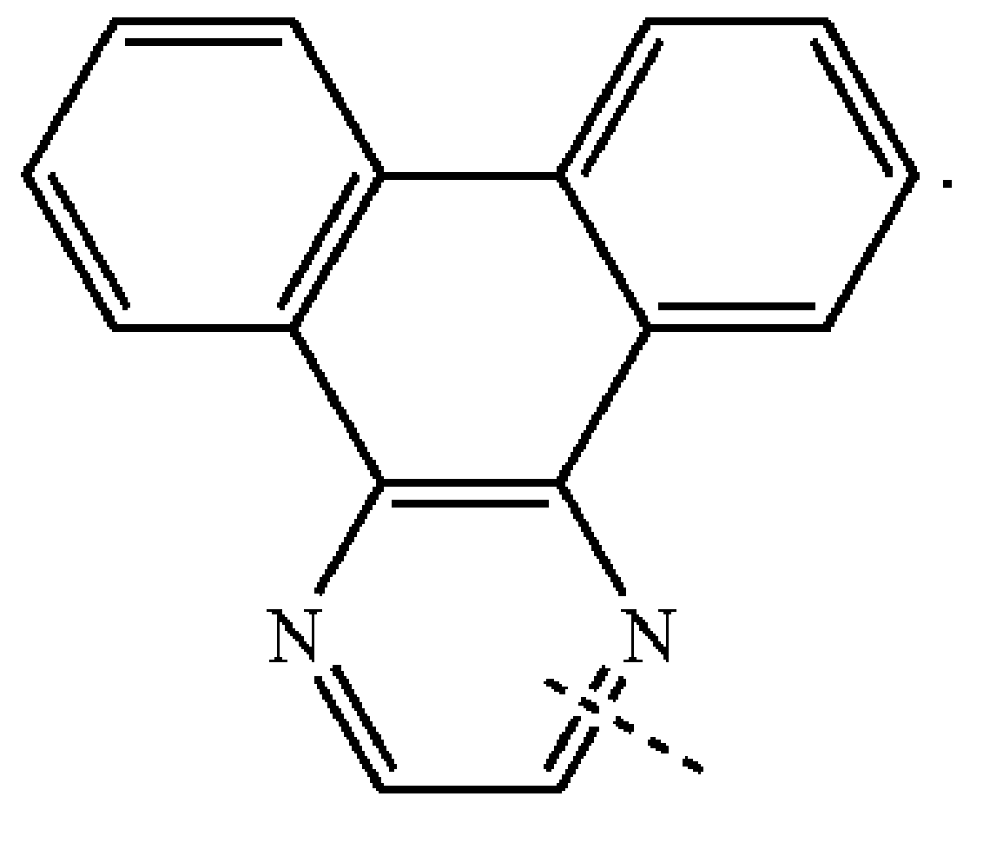




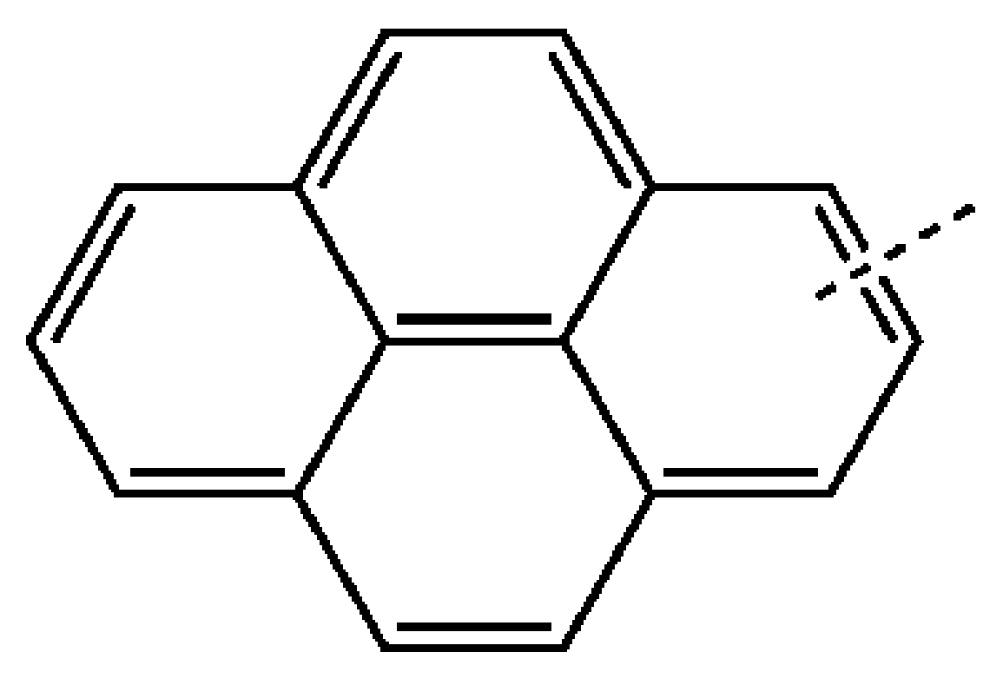


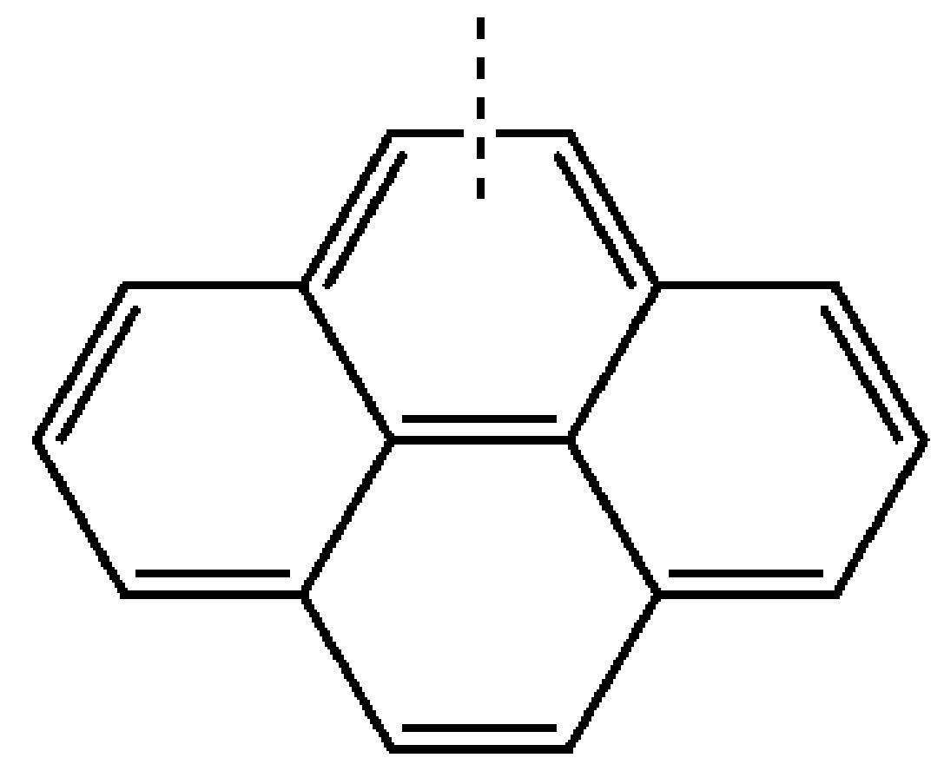






5. The compound of claim **1**, wherein A is selected from the group consisting of:





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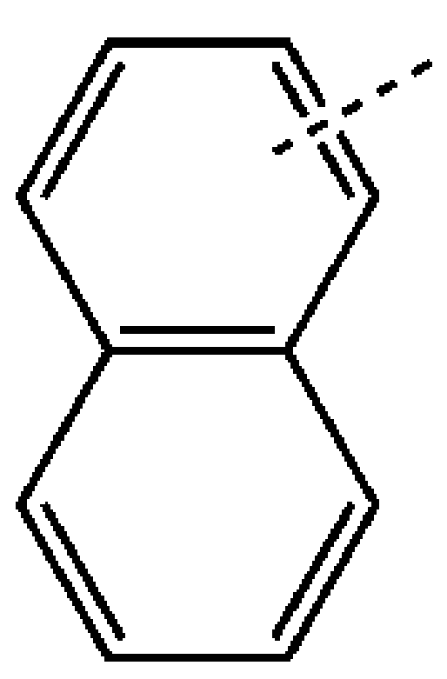
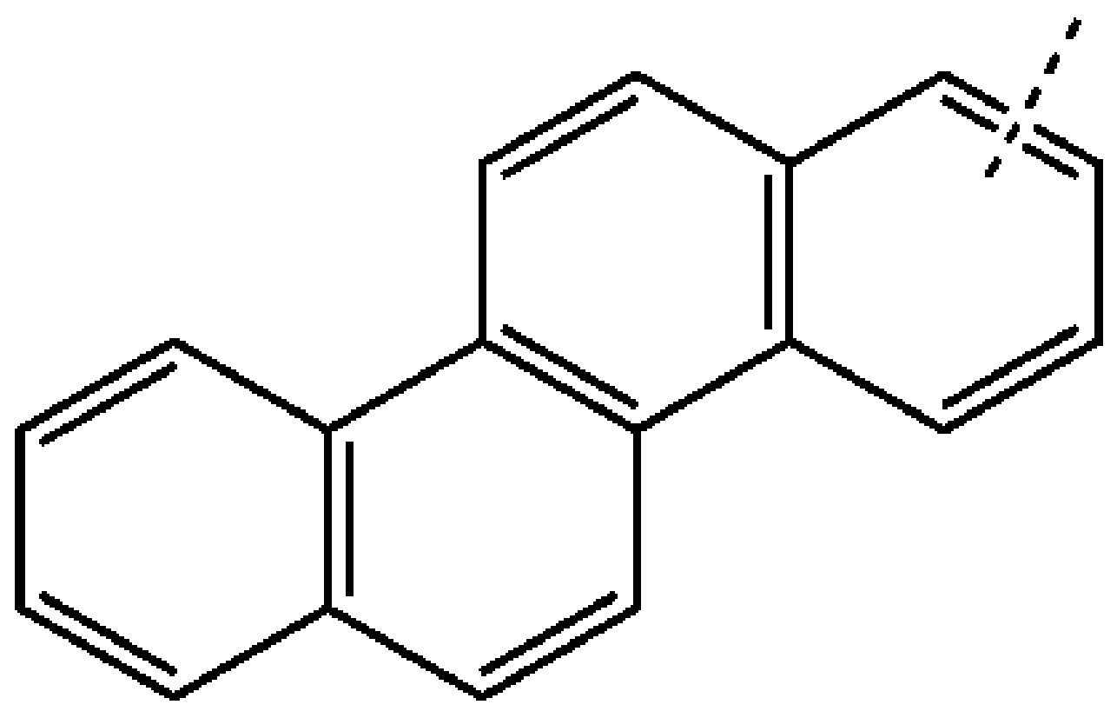
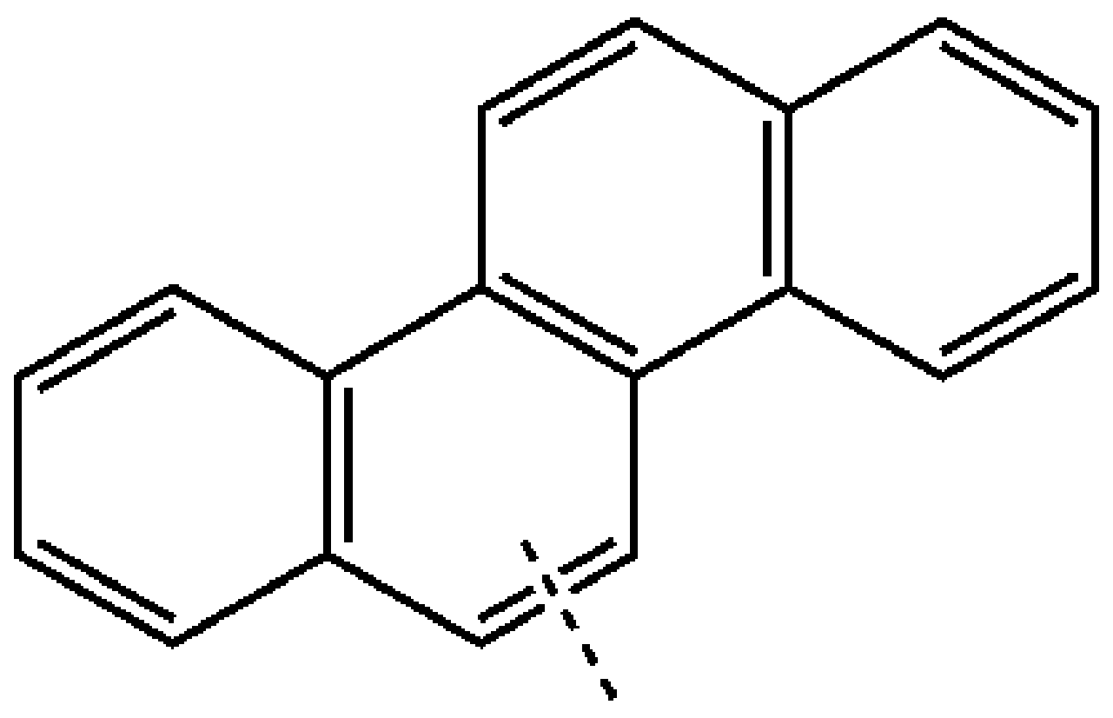
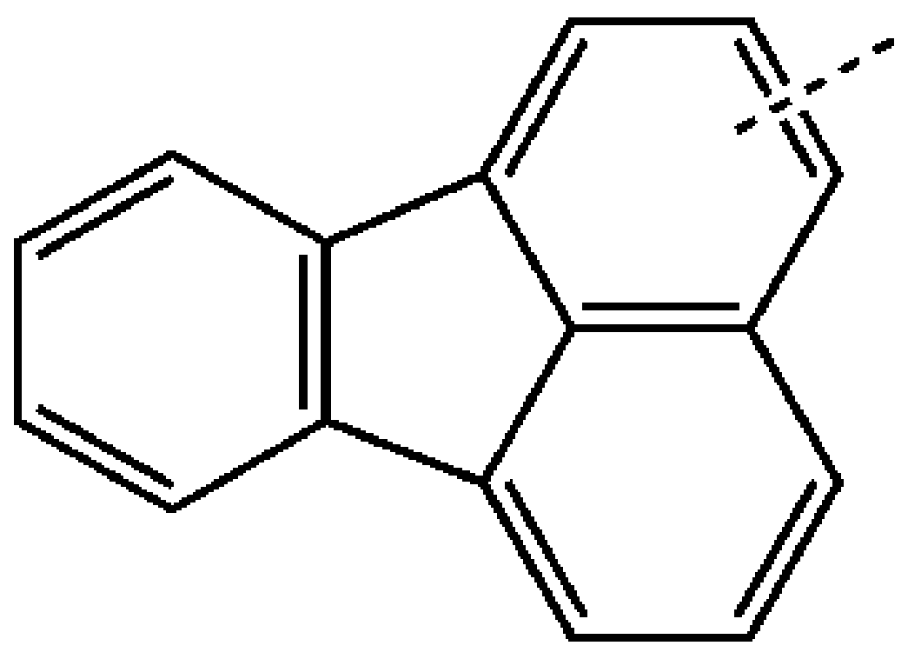
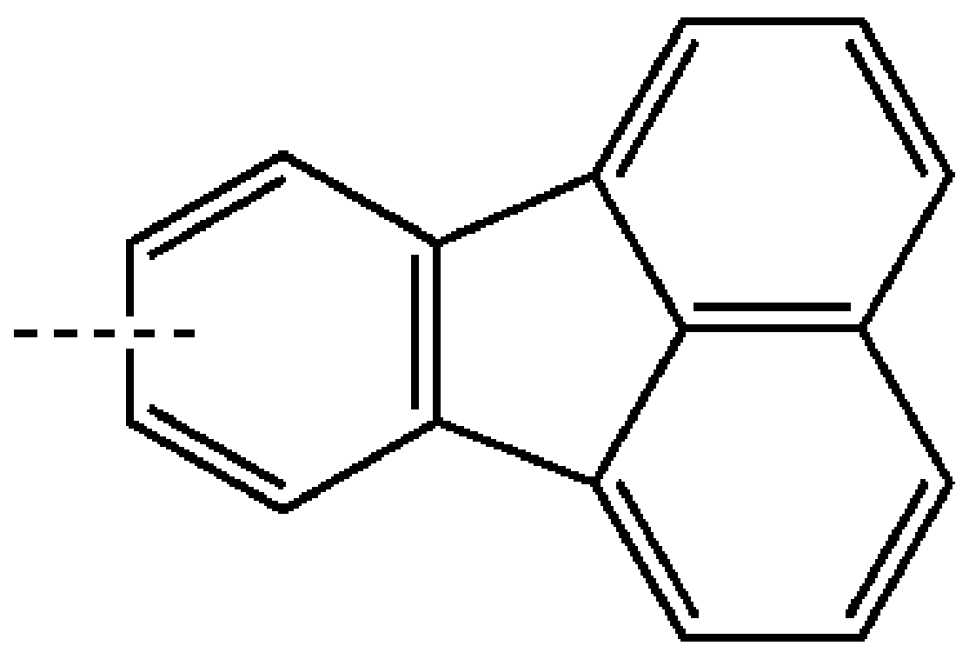
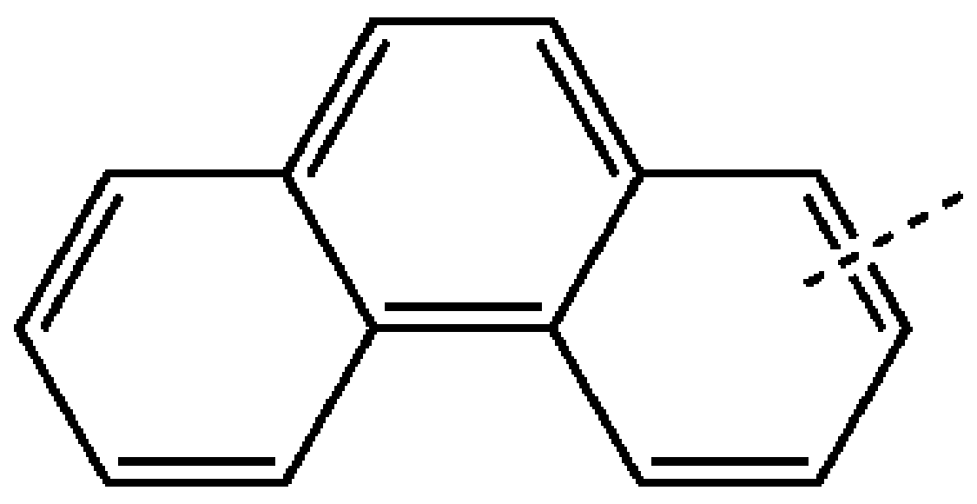
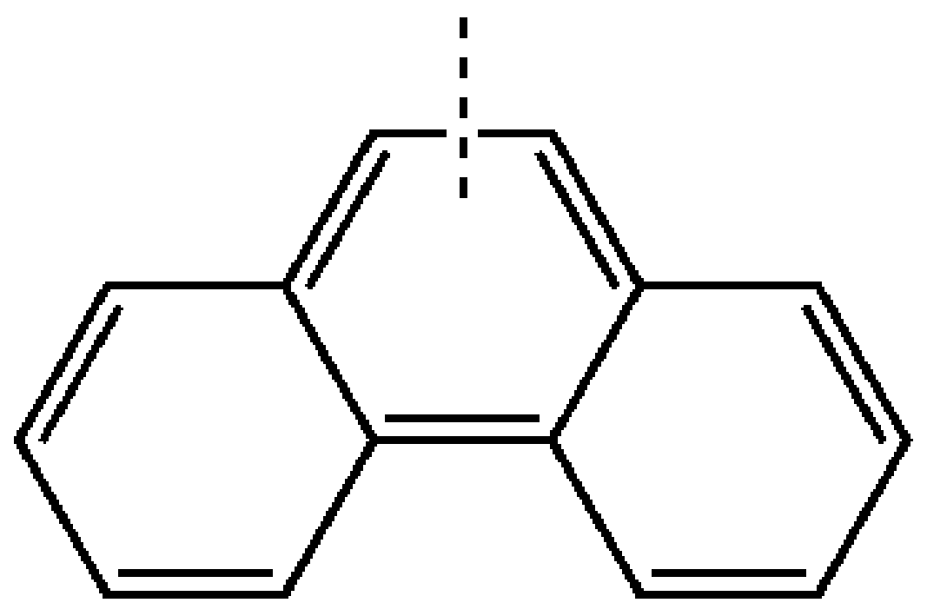
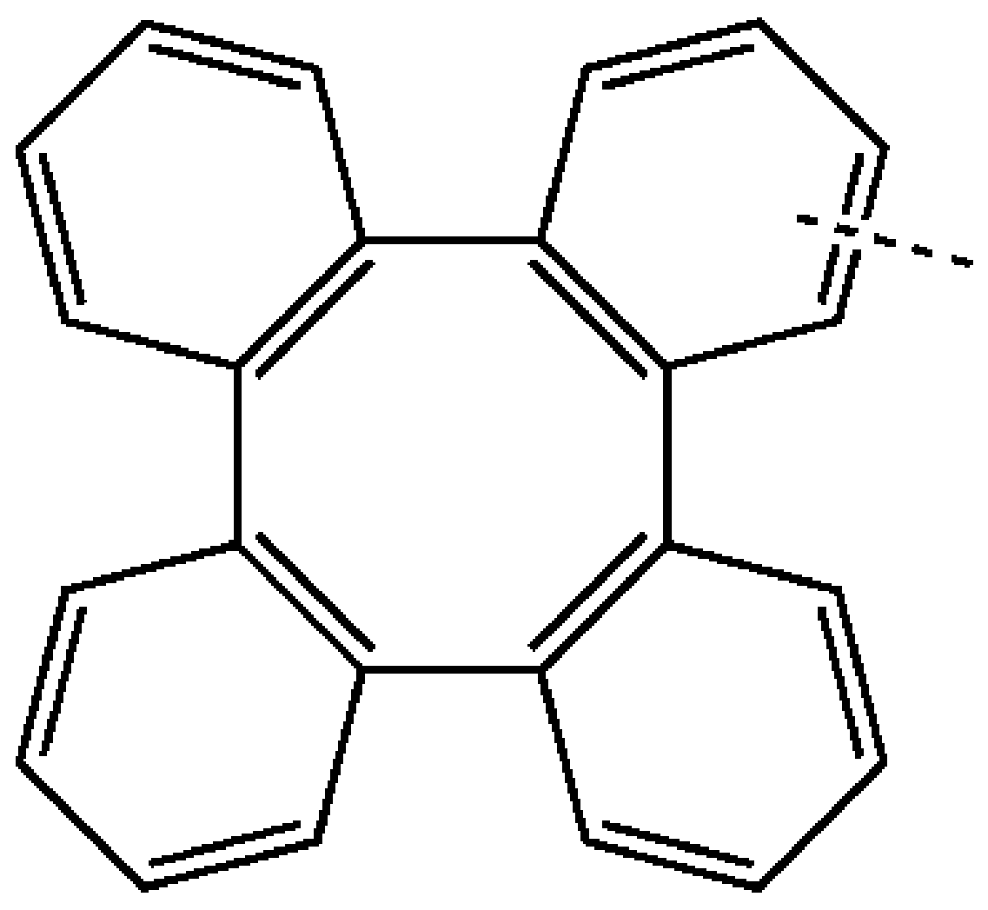
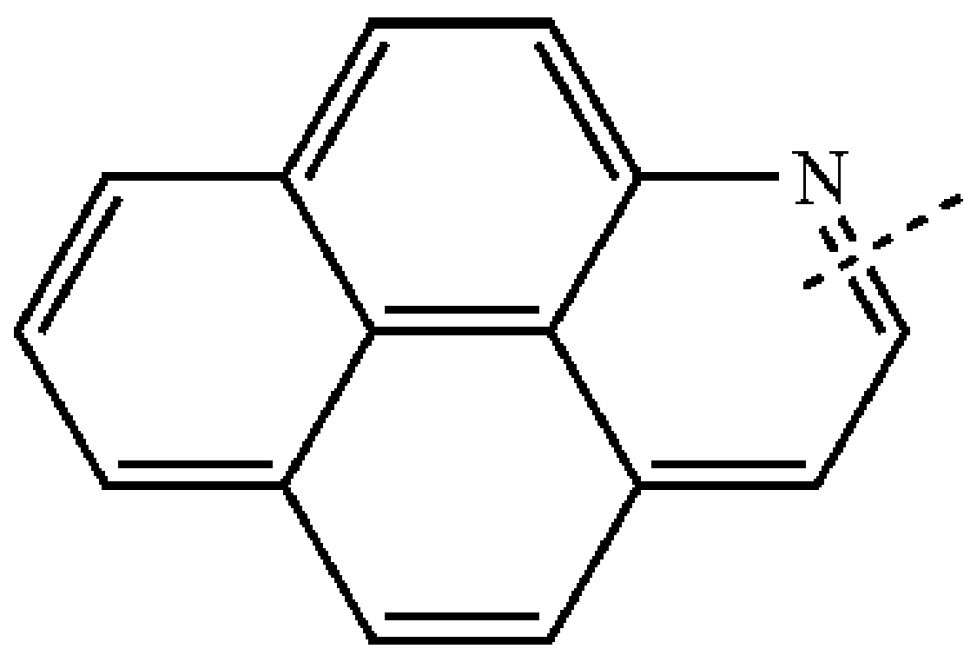
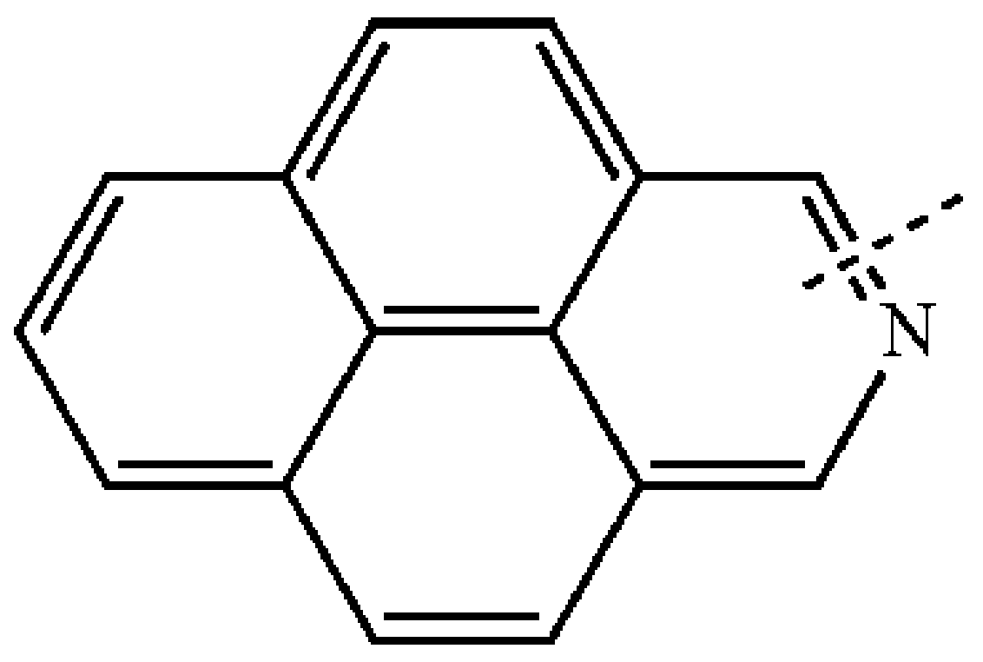
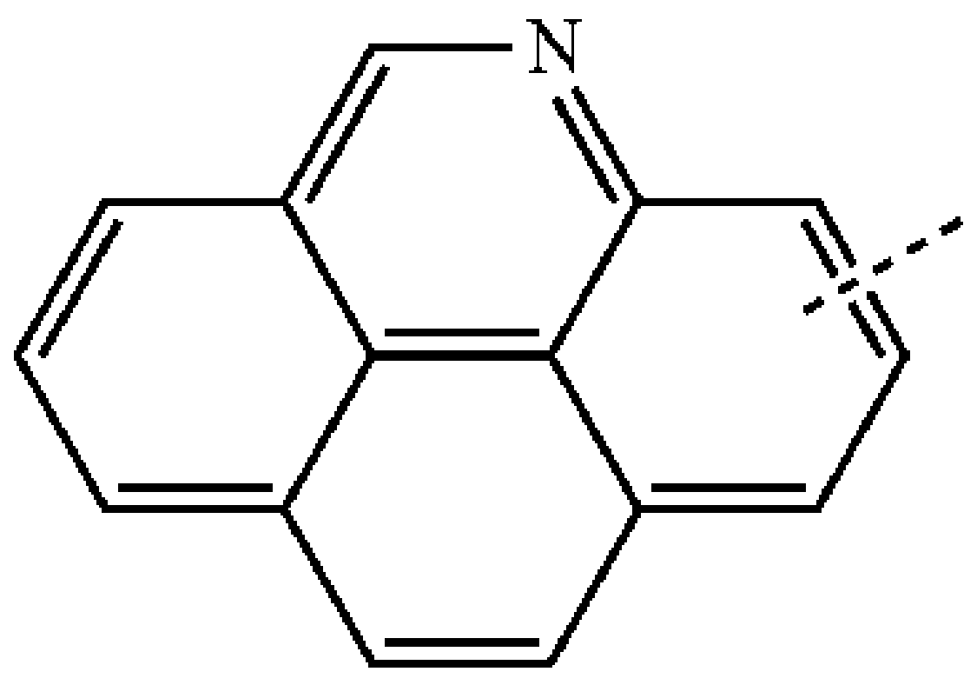
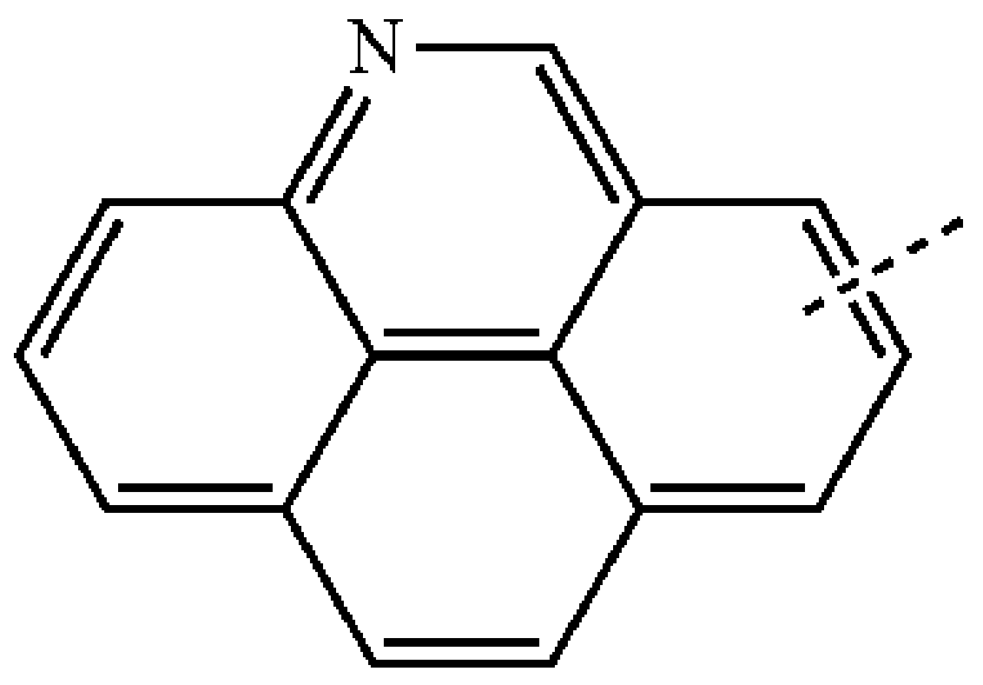
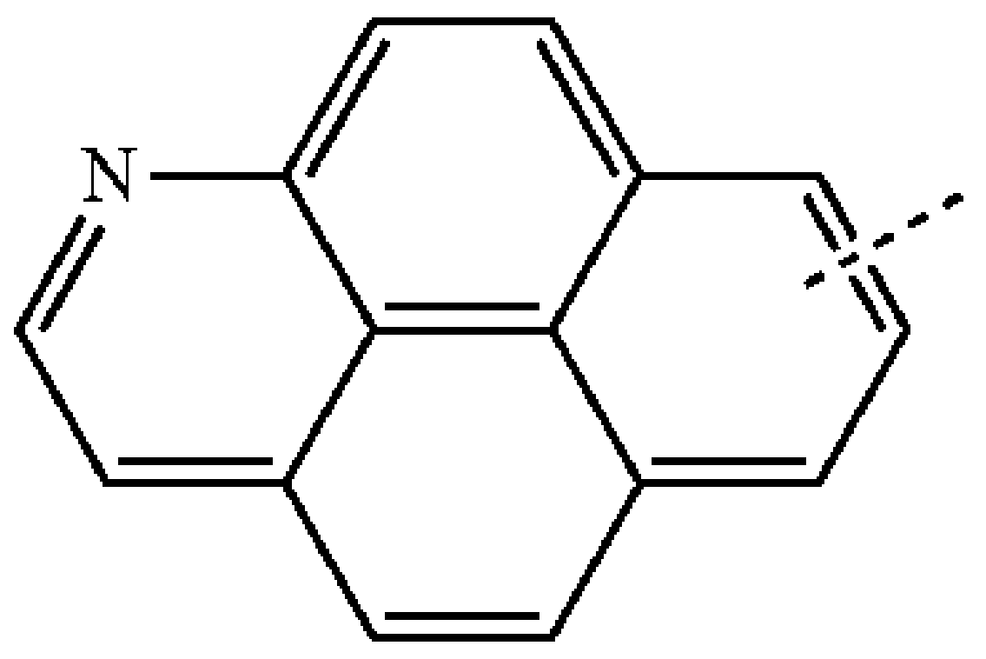
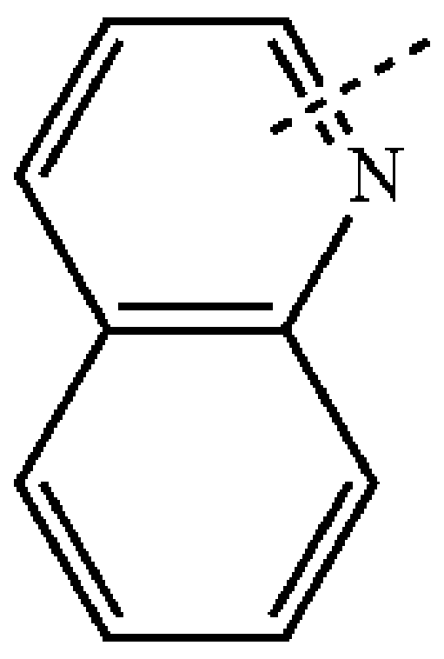
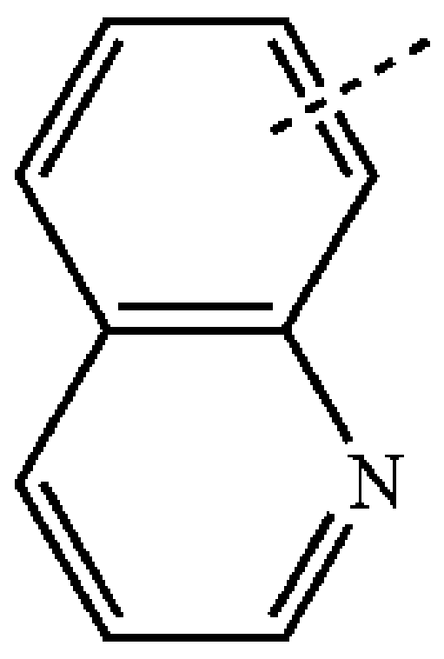
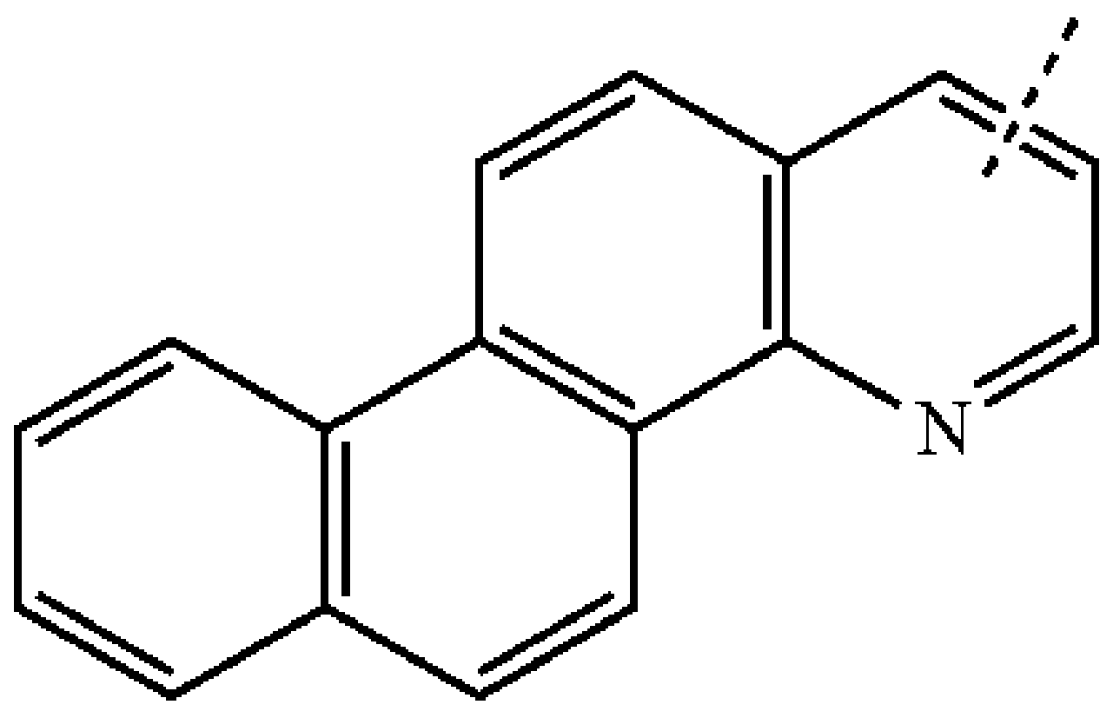
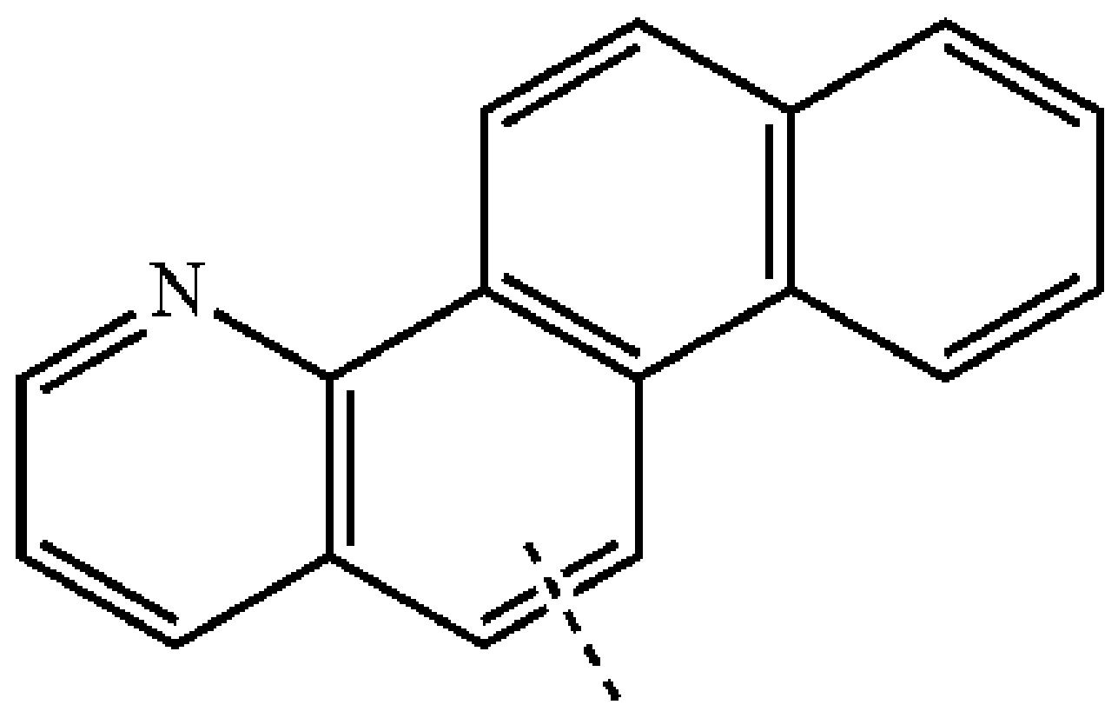
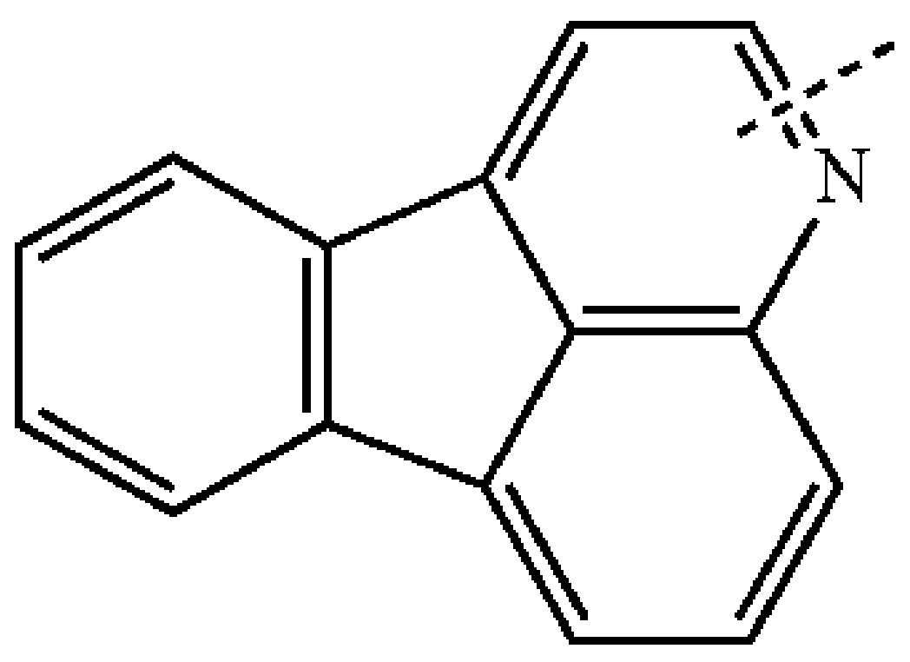
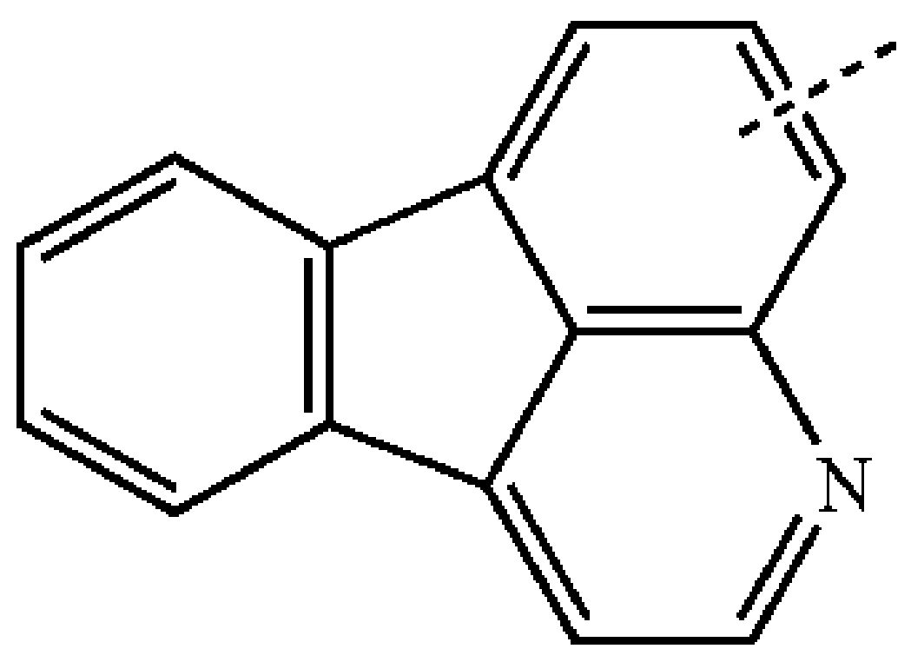
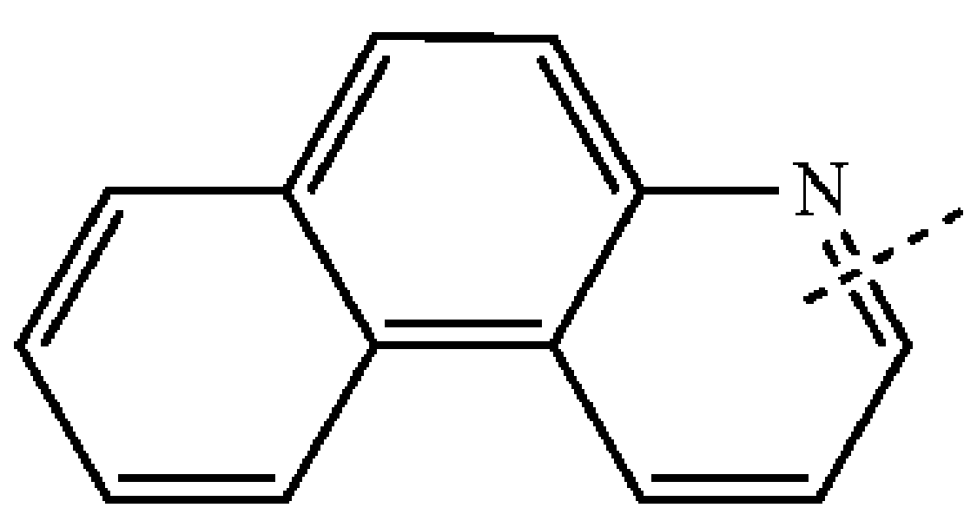
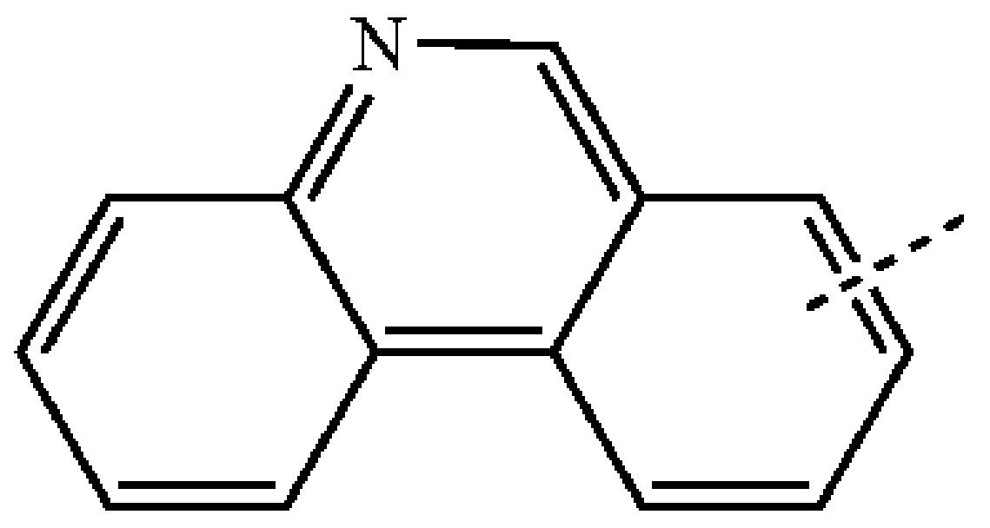

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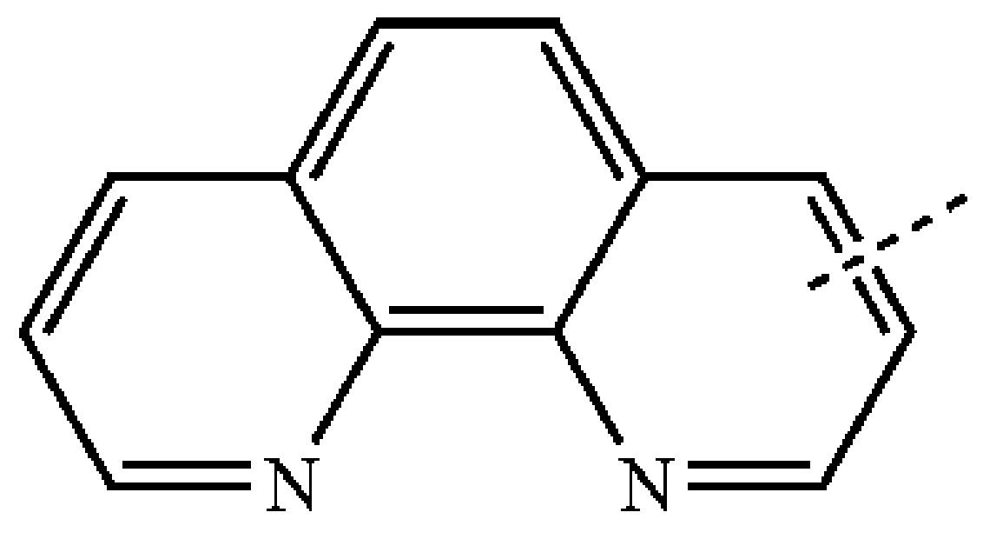
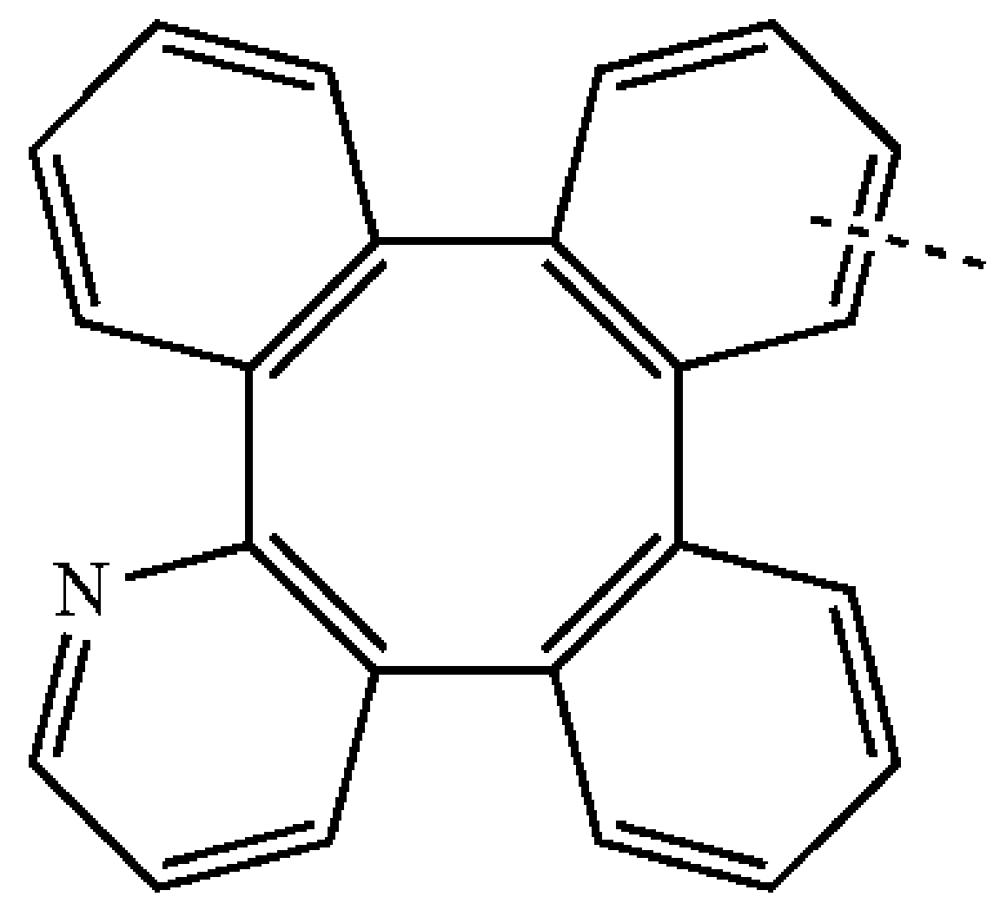
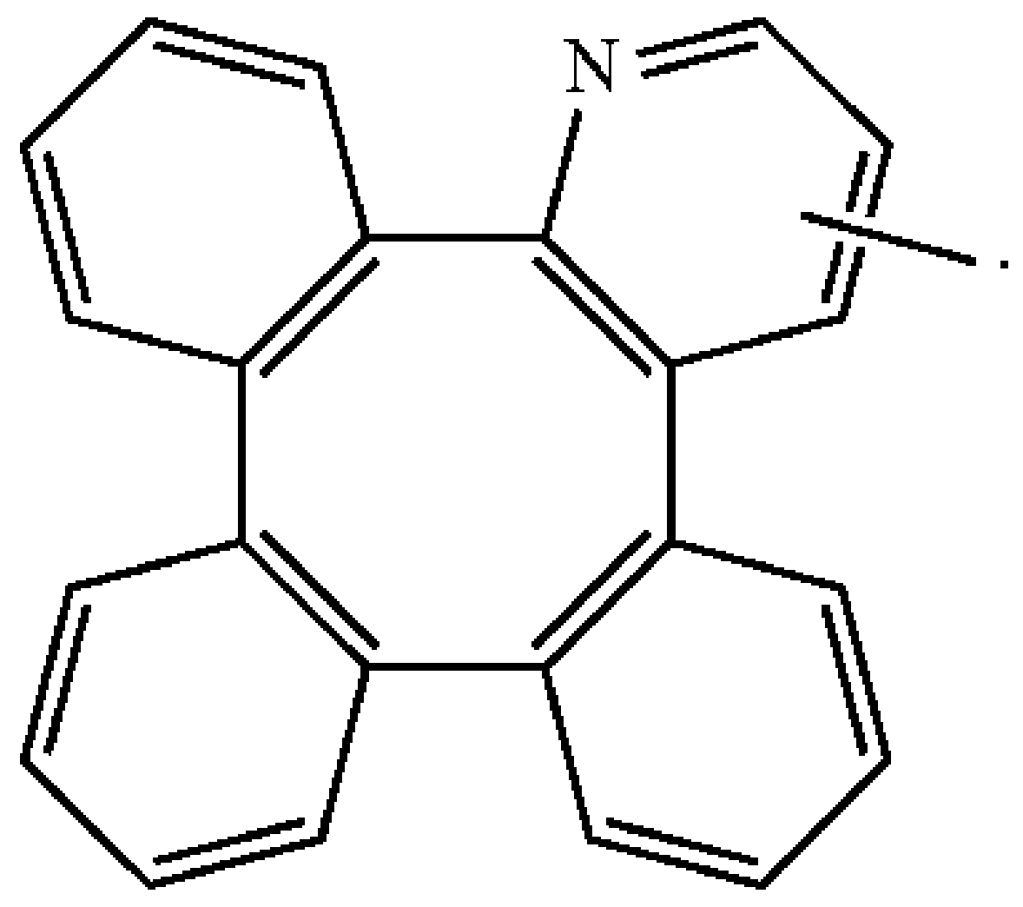
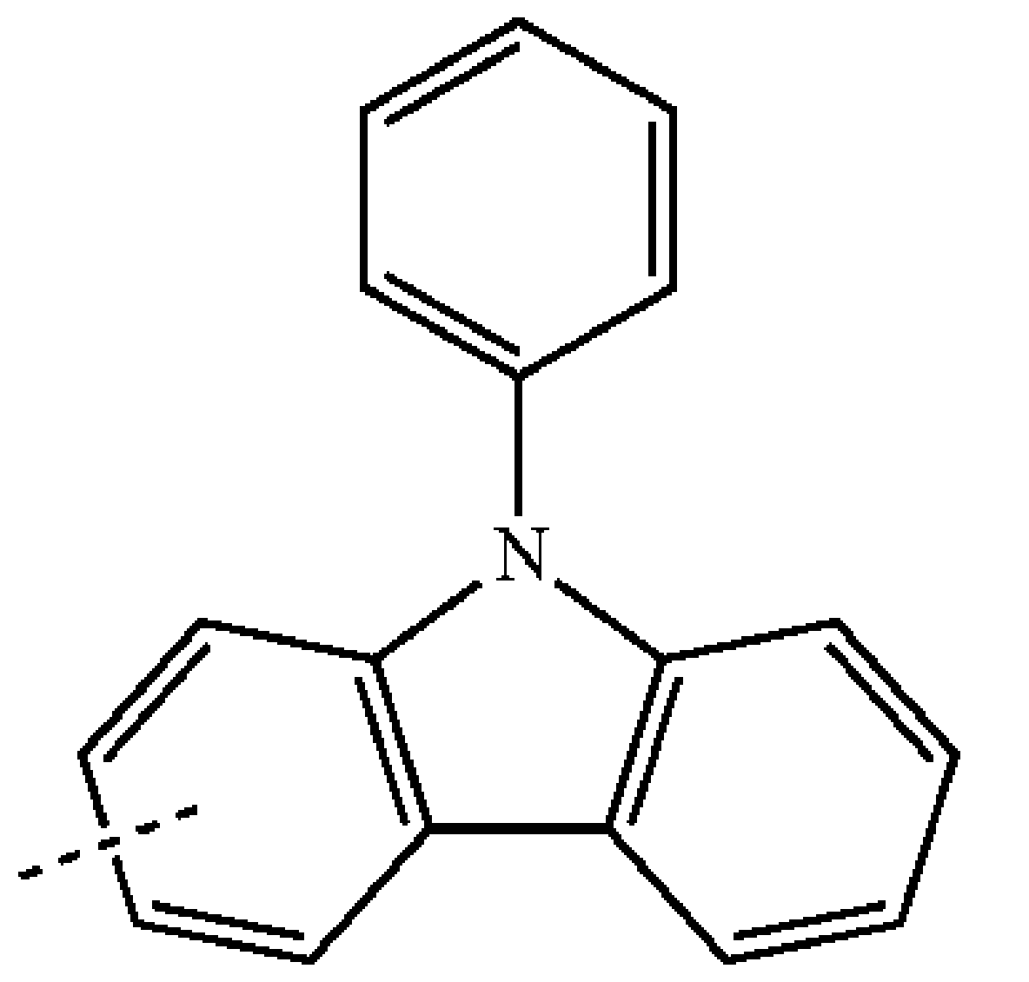
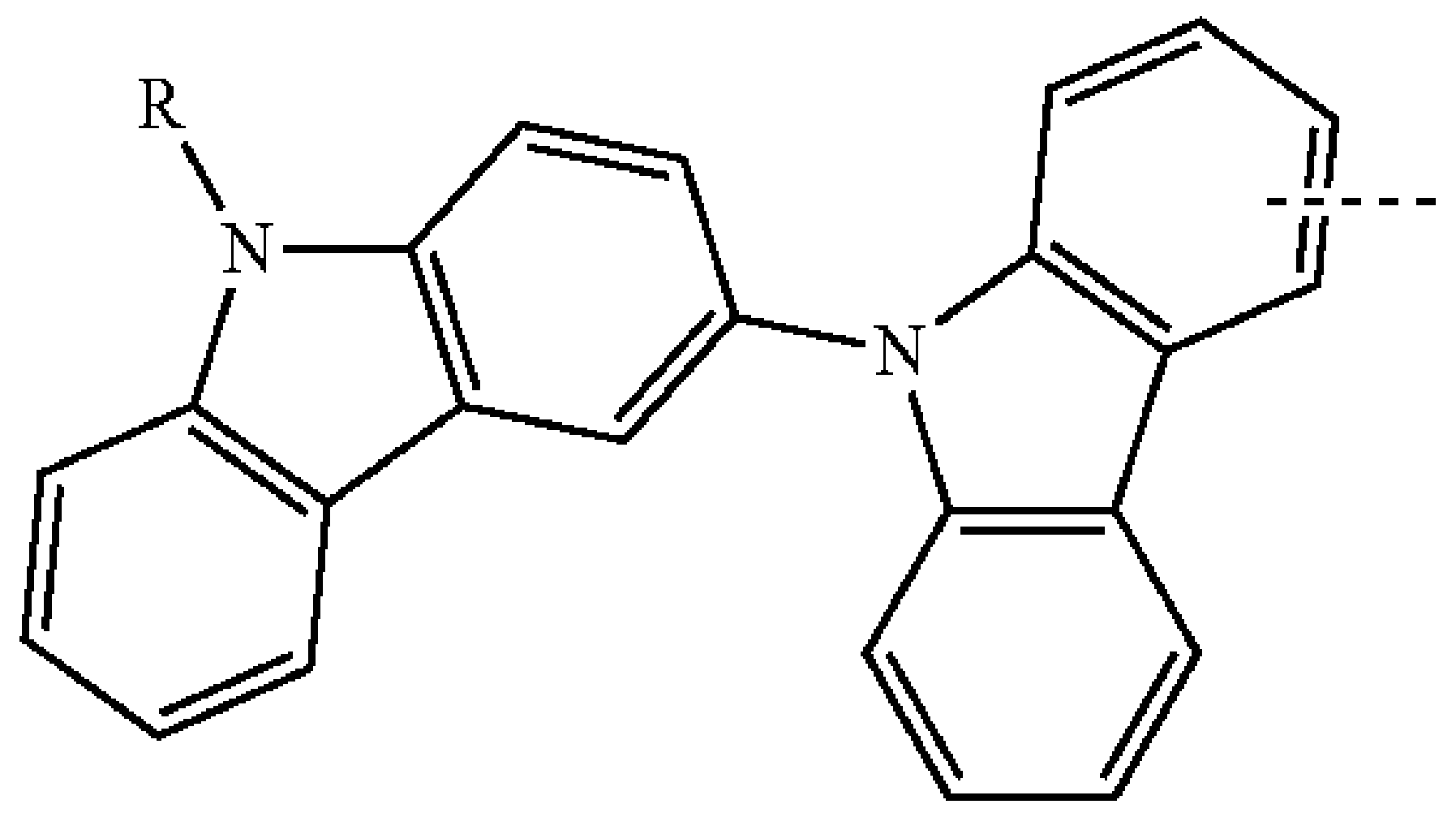
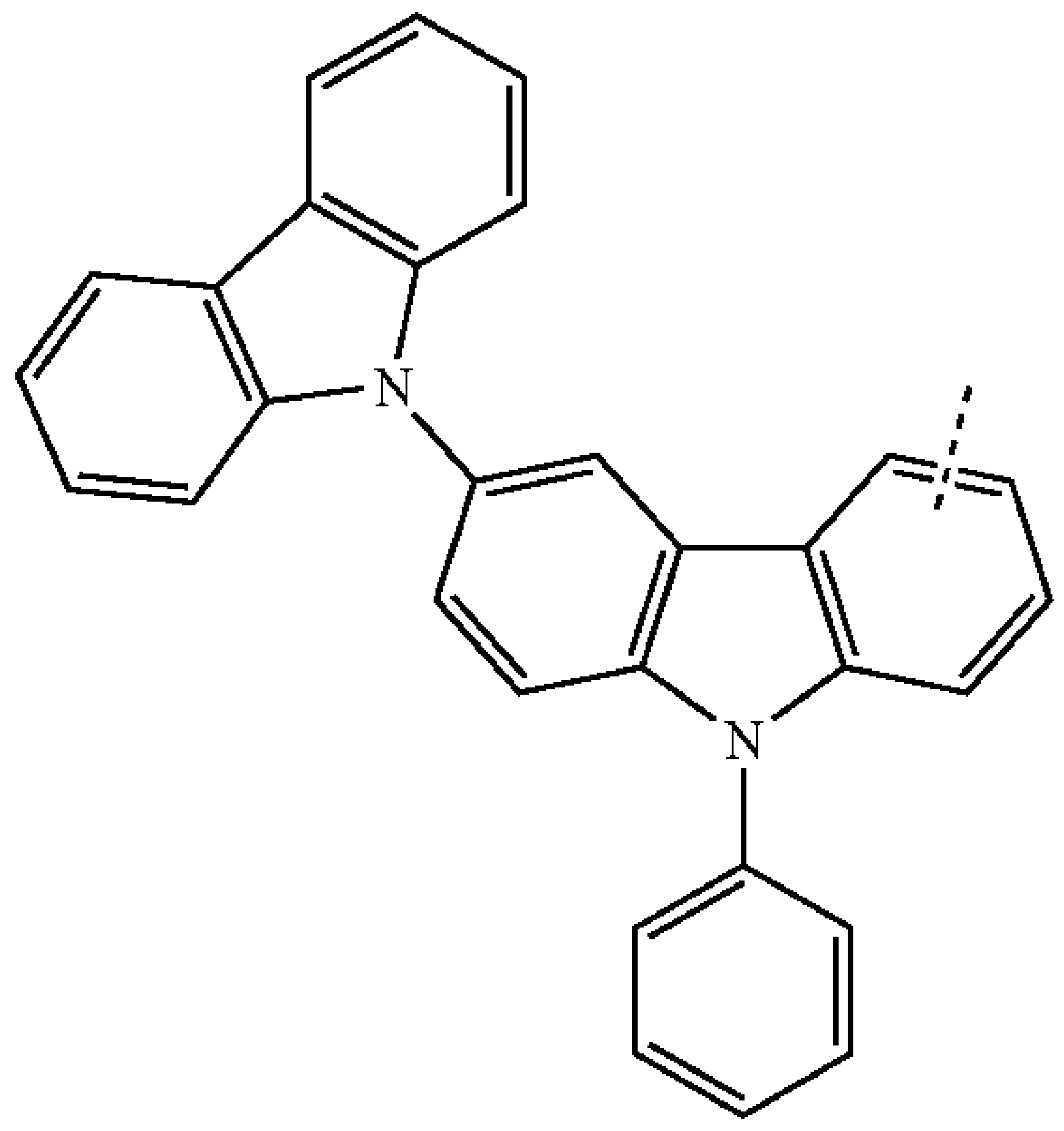
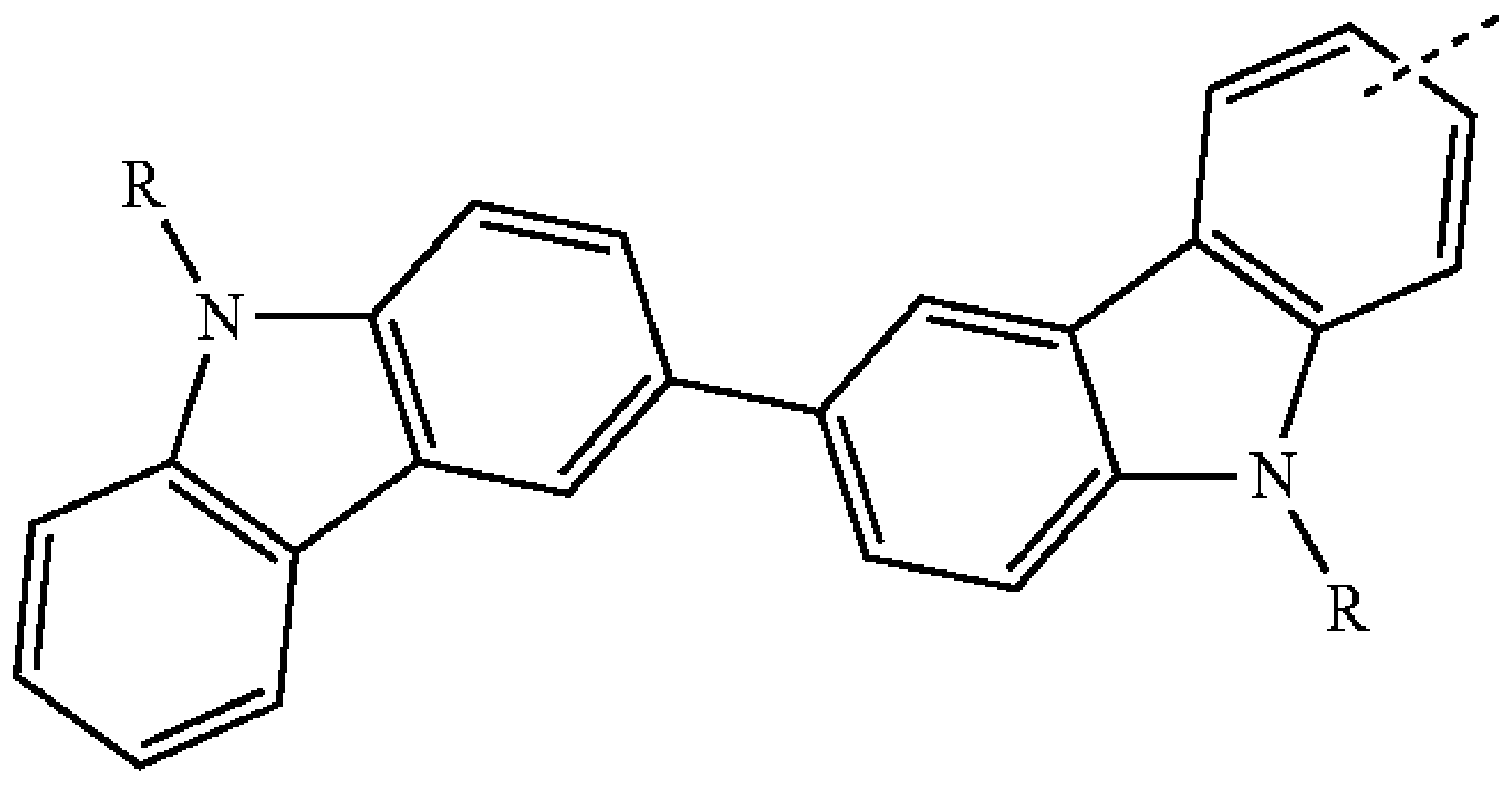




6. The compound of claim 1, wherein B is selected from the group consisting of:

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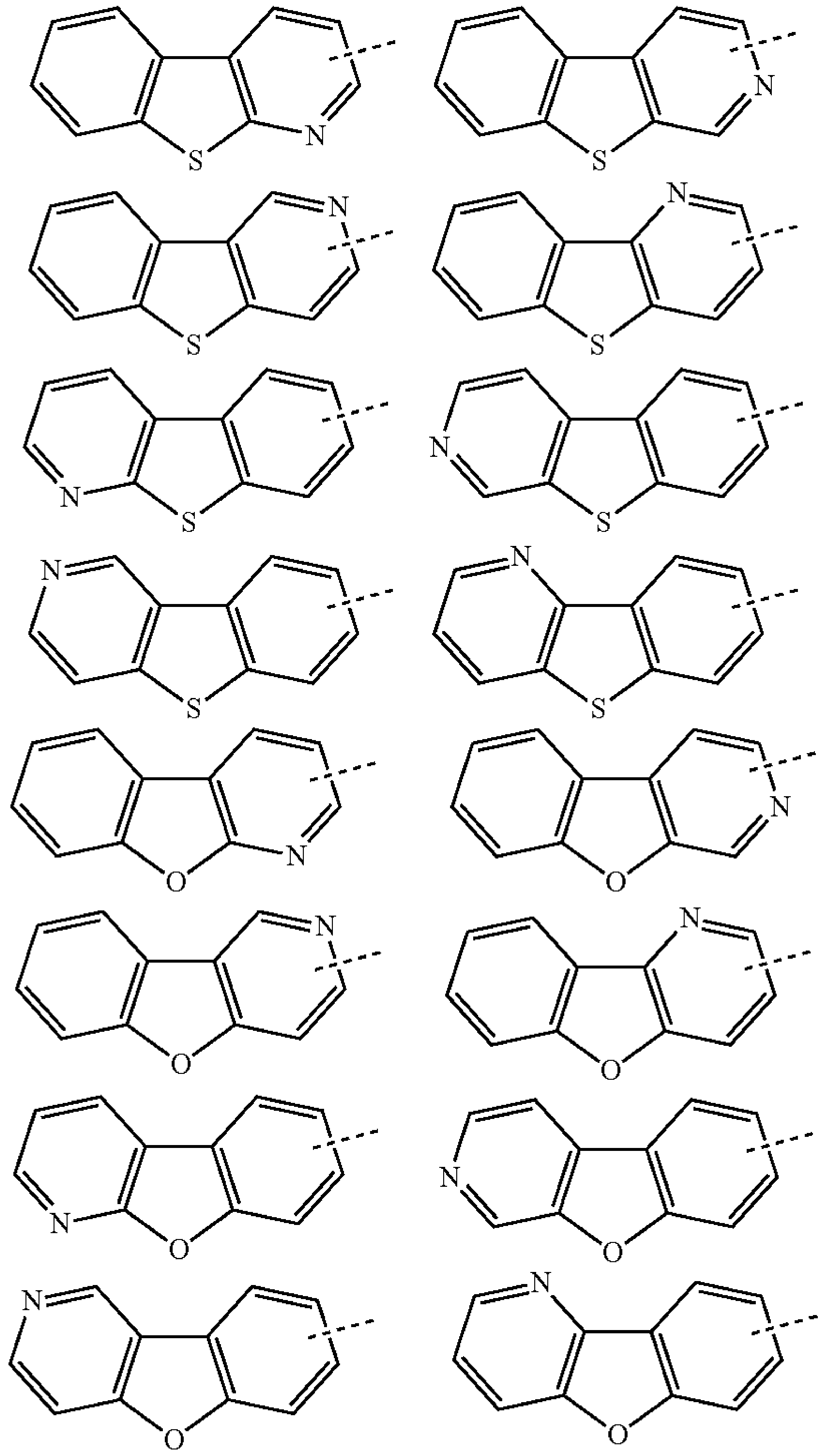
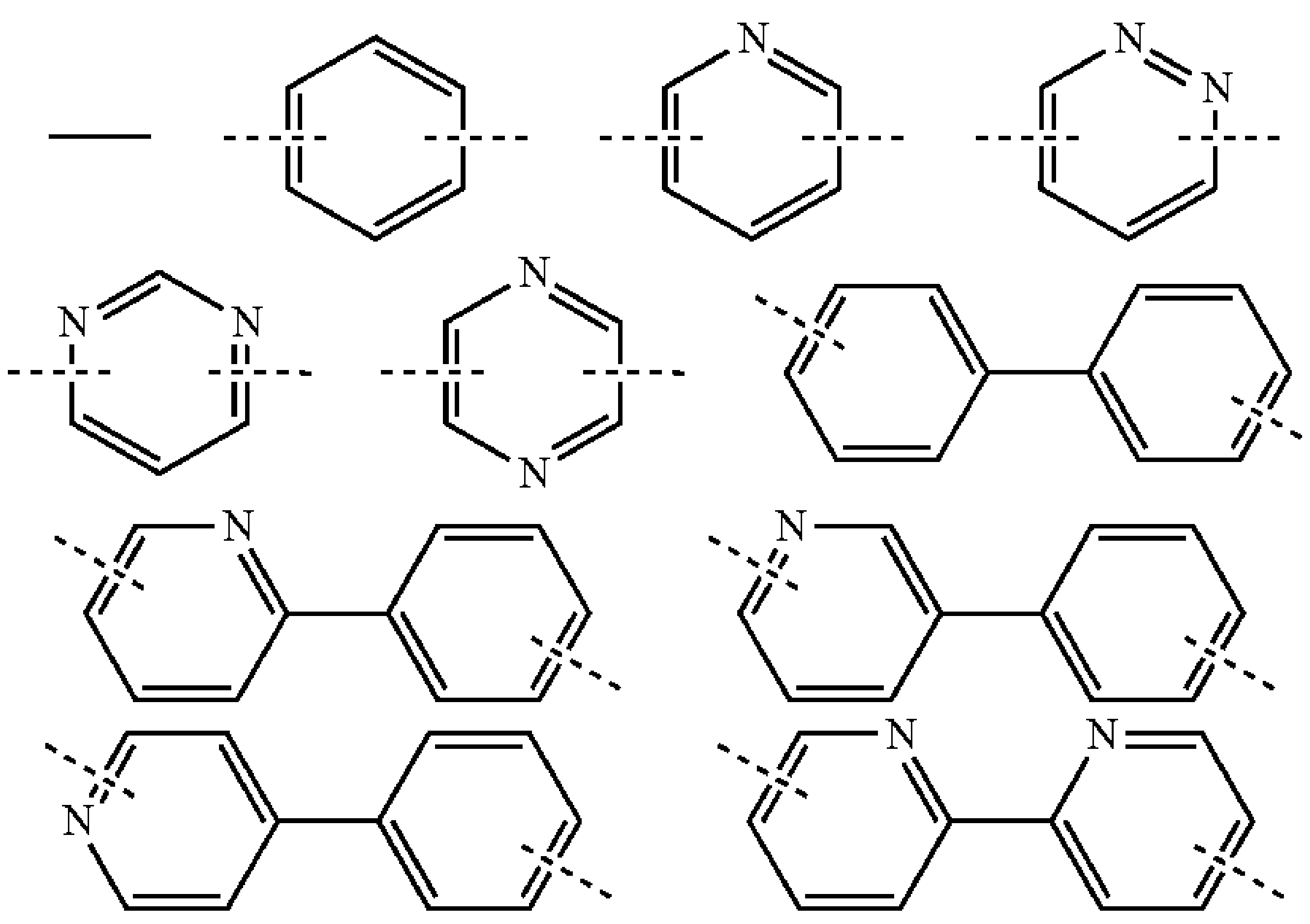


wherein Y_1 is selected from the group consisting of O, S, and Se;

wherein R is selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof.

7. The compound of claim **1**, wherein L is independently selected from the group consisting of:



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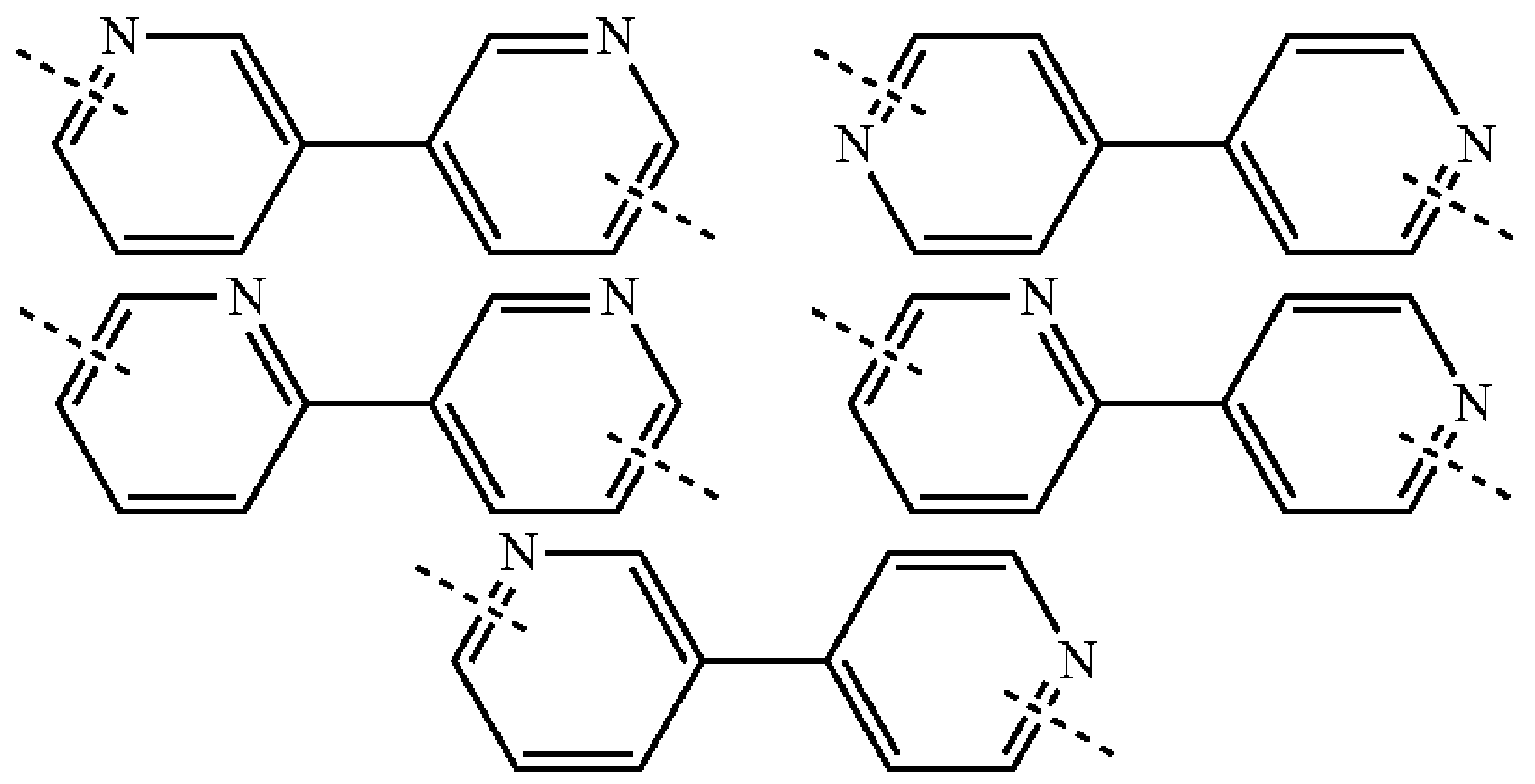
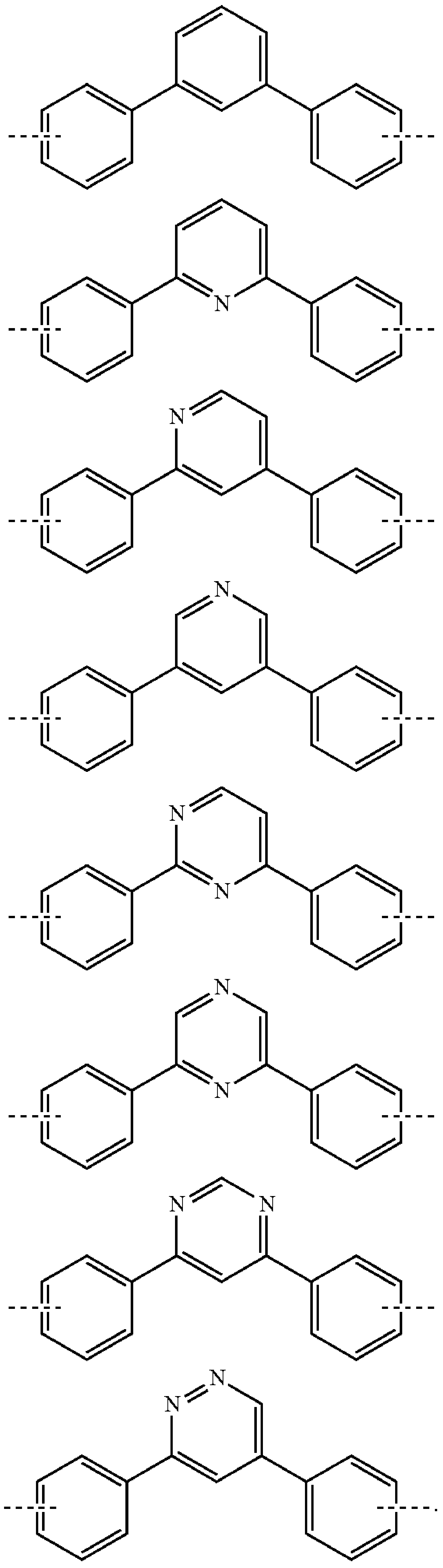




8. The compound of claim **1**, wherein A is tripheynylene.

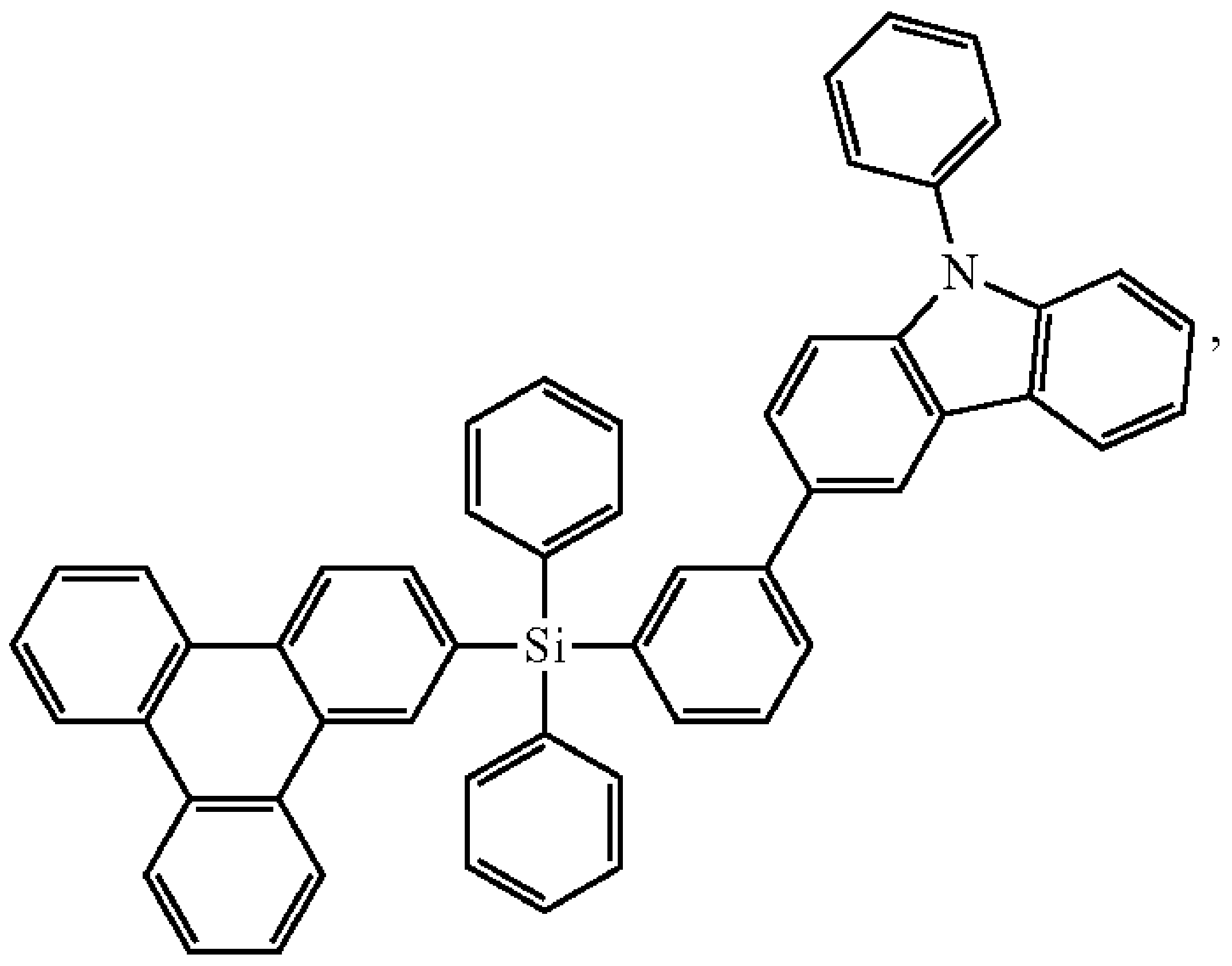
9. The compound of claim **1**, wherein A is pyrene.

10. The compound of claim **1**, wherein Ar and Ar' are phenyl.

11. The compound of claim **1**, wherein L is phenyl.

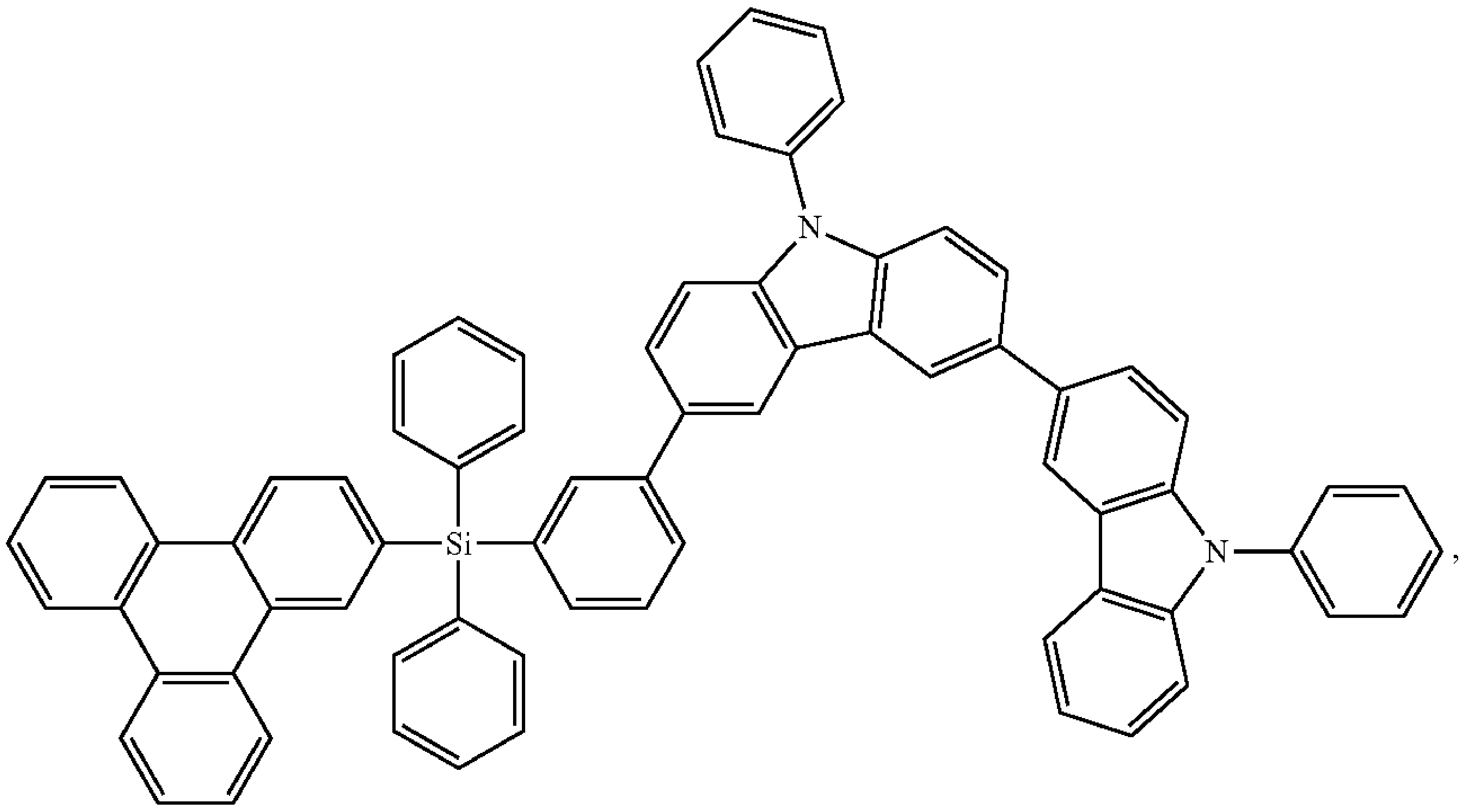
12. The compound of claim **1**, whereto the compound is selected from the group consisting of:

Compound 6

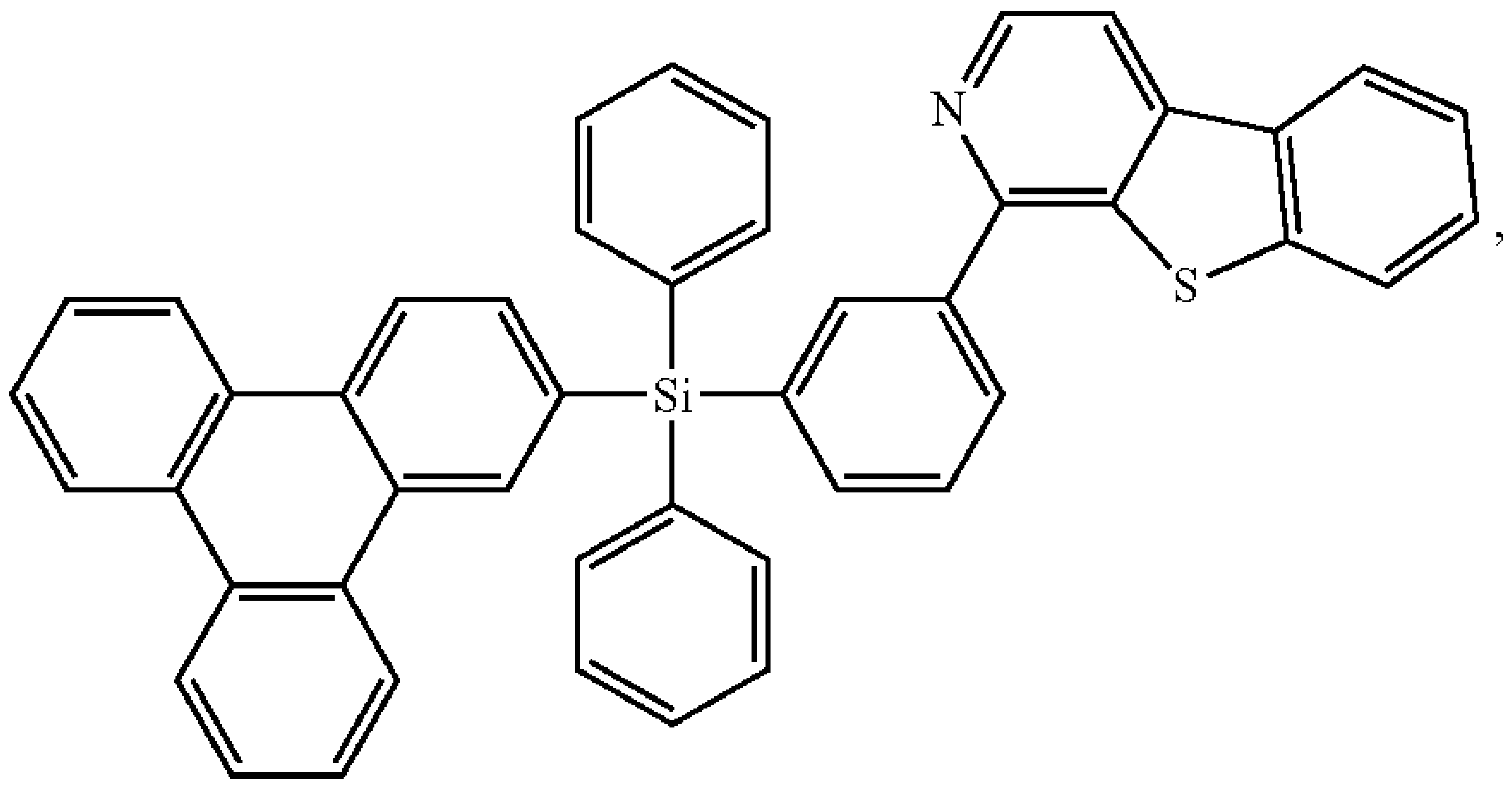


, and

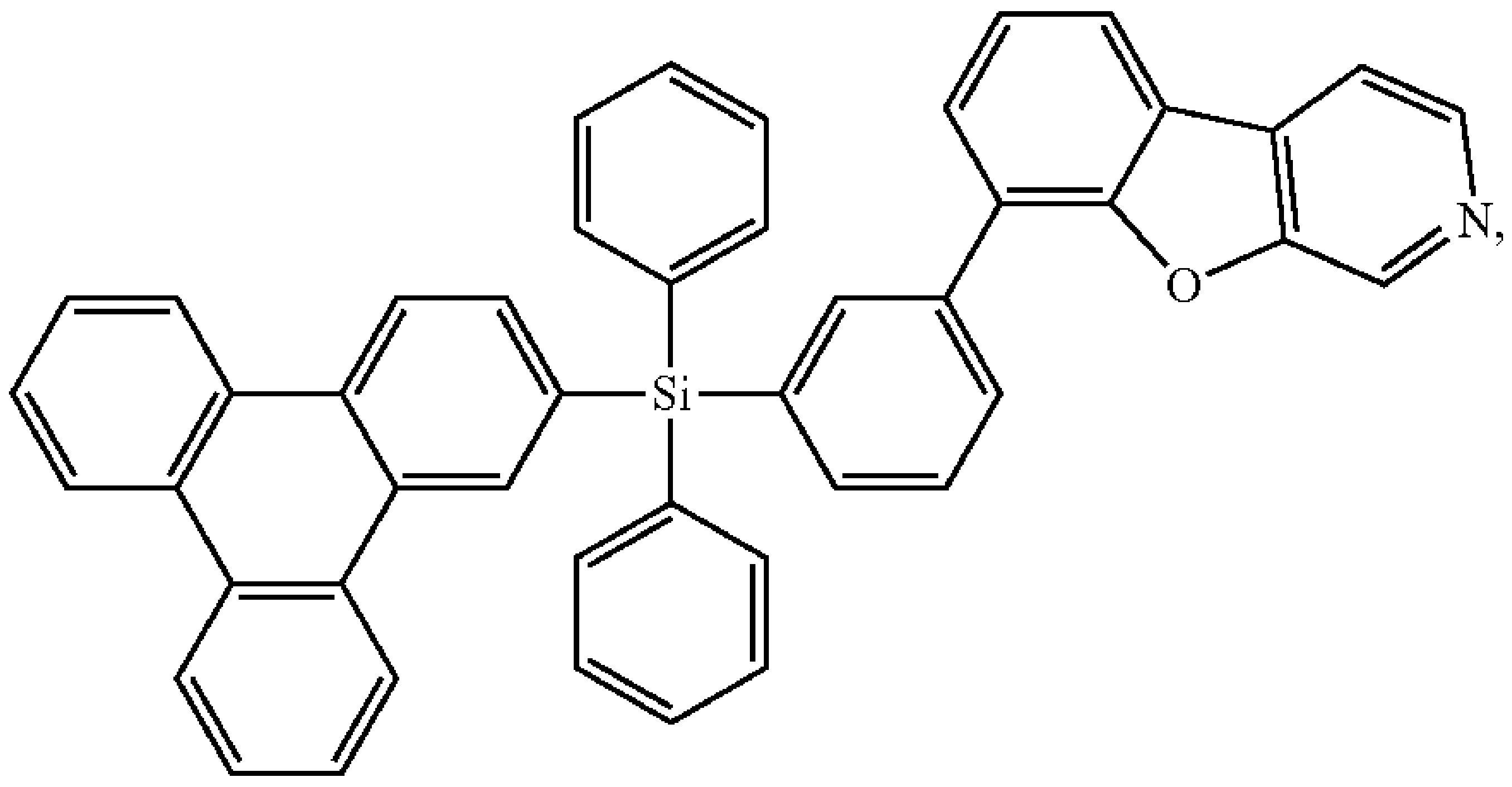
Compound 12



Compound 17



Compound 18



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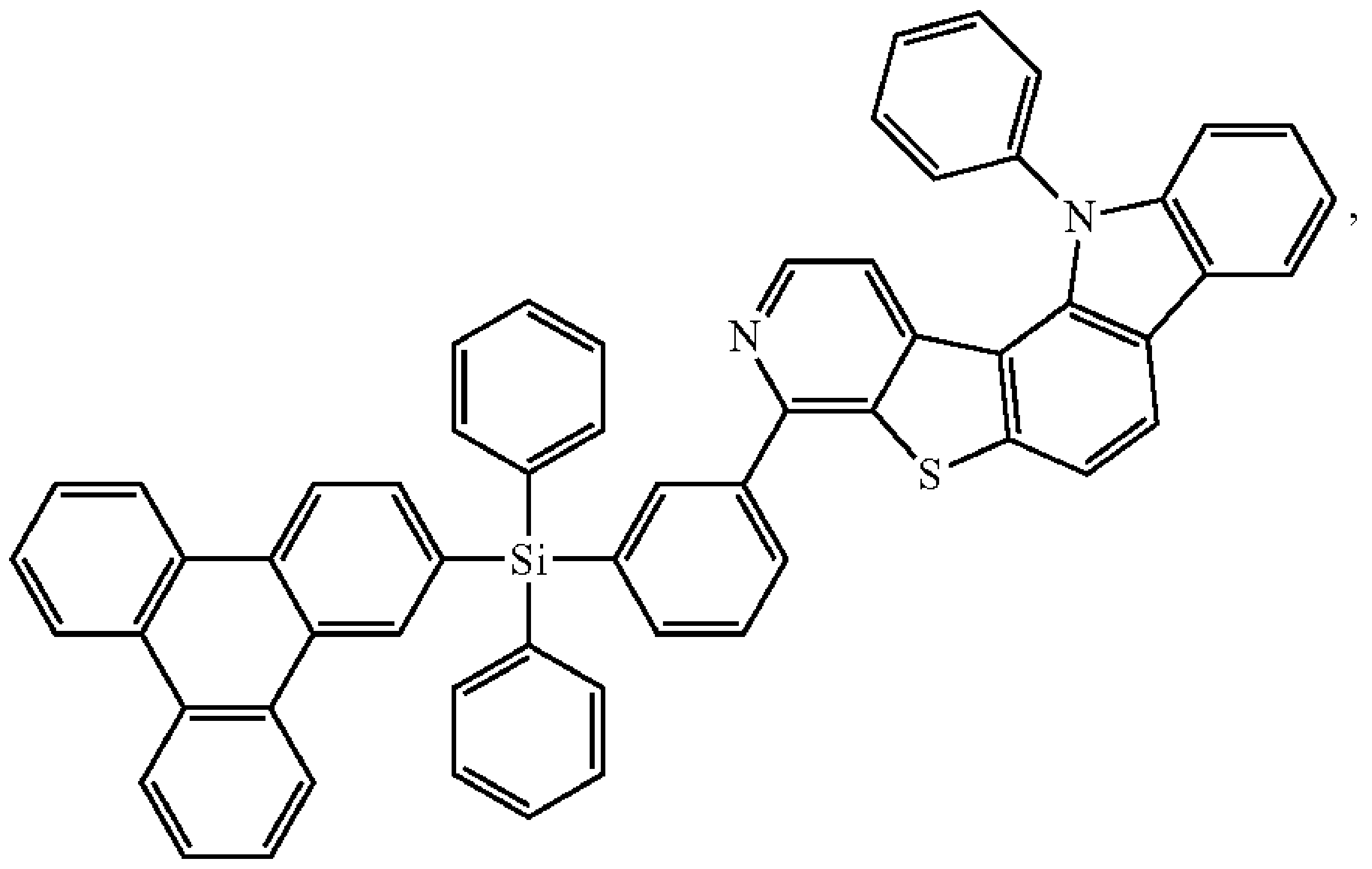
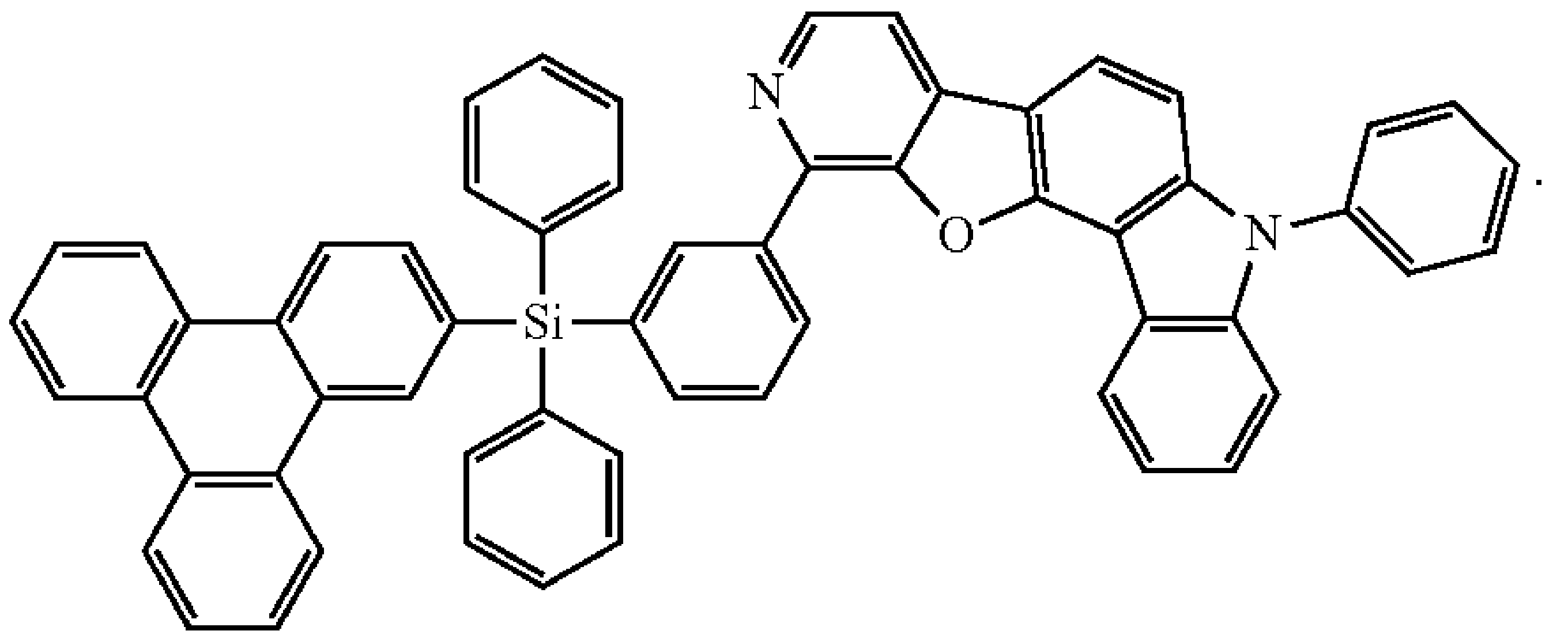


Compound 20



Compound 22

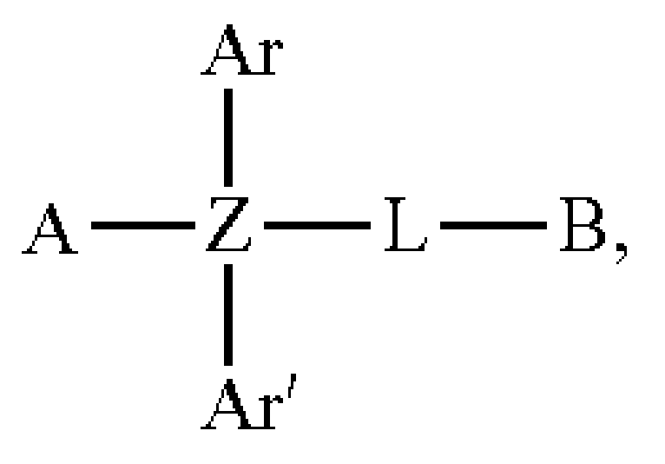
13. A first device comprising an organic light-emitting device, further comprising:

an anode;

a cathode; and

an organic layer, disposed between the anode and the cathode, comprising a compound having the formula:

Formula I



$$A-\underset{Ar'}{\overset{Ar}{Z}}-L-B,$$

wherein Ar and Ar' are independently selected from the group consisting of phenyl, biphenyl, naphthalene, dibenzothiophene and dibenzofuran, which are optionally further substituted;

Z is selected from Si and Ge;

L is a single bond or comprises an aryl or heteroaryl group having from 5-20 carbon atoms, which is optionally further substituted;

A is a group directly bonded to Z and is selected from the group consisting of triphenylene, tetraphenylene, pyrene, naphthalene, fluoranthene, chrysene, phenanthrene, azatriphenylene, azatetraphenylene, azapyrene, azanaphthalene, azafluoranthene, azachrysene, azaphenanthrene, and combinations thereof, which are optionally further substituted with one or more groups selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, aryl, aryloxy, and combinations thereof;

B is a group selected from the group consisting of carbazole, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene, azadibenzoselenophene, and combinations thereof, which are optionally further substituted with one or more groups selected from hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

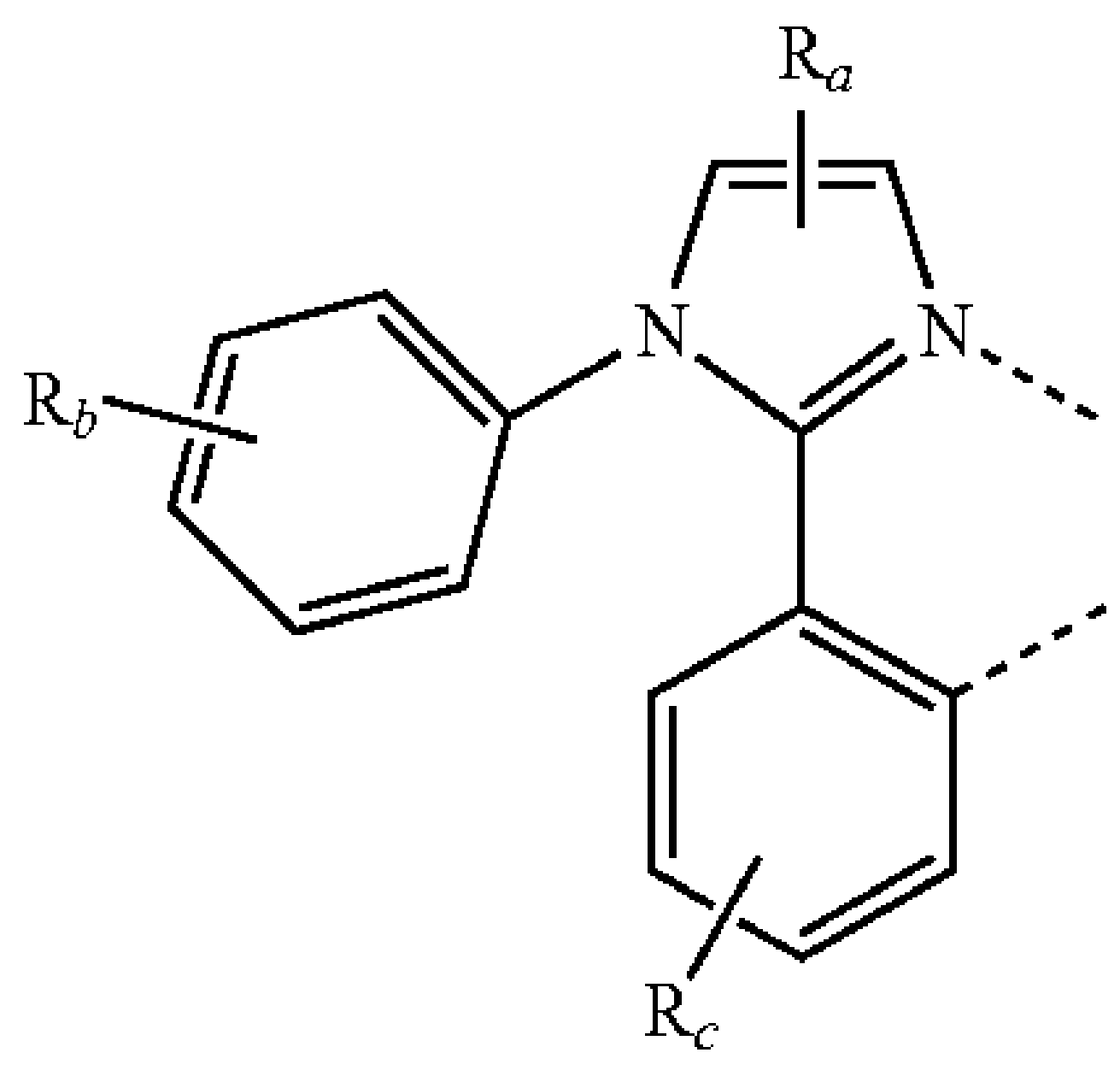
wherein the substitution is optionally fused to the carbazole, dibenzoselenophene, aza-carbazole, aza-dibenzofuran, aza-dibenzothiophene or azadibenzoselenophene group

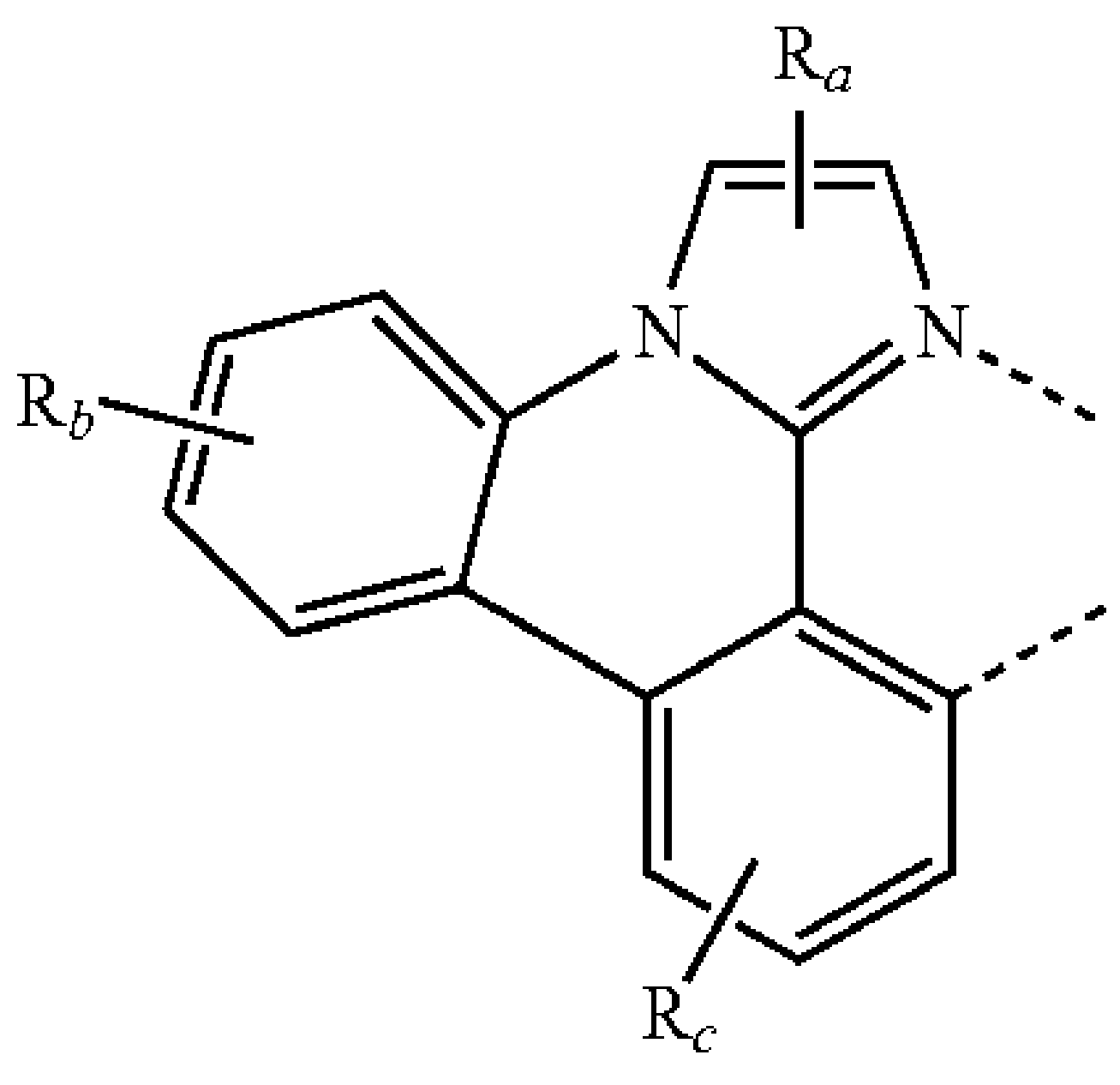
wherein when B is carbazole, the carbazole group is connected to L through a ring carbon.

14. The first device of claim 13, wherein the organic layer is an emissive layer and the compound of Formula I is a host.

15. The first device of claim 13, wherein the organic layer further comprises an emissive dopant.

16. The first device of claim 15, wherein the emissive dopant is a transition metal complex having at least one ligand selected from the group consisting of:





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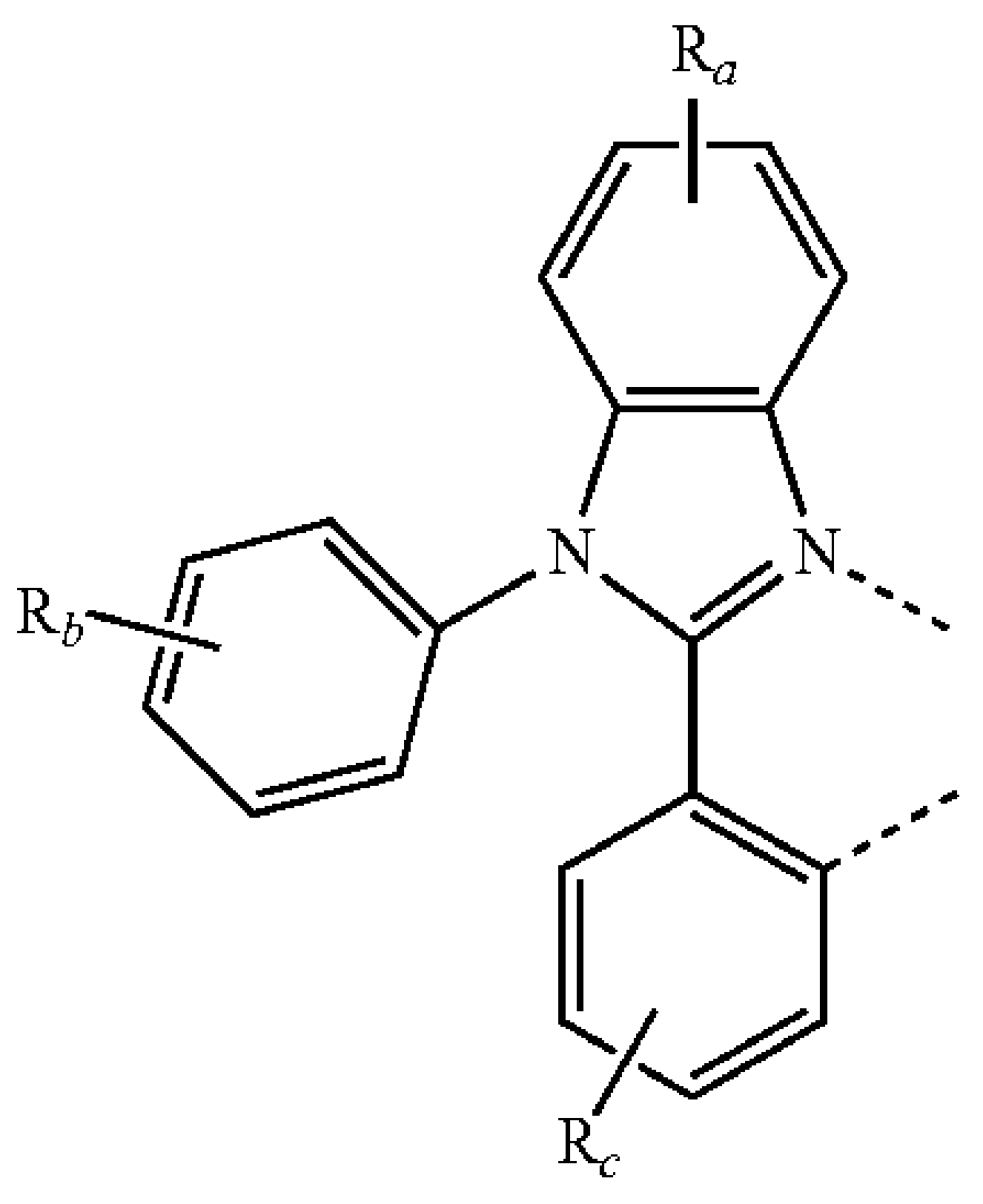
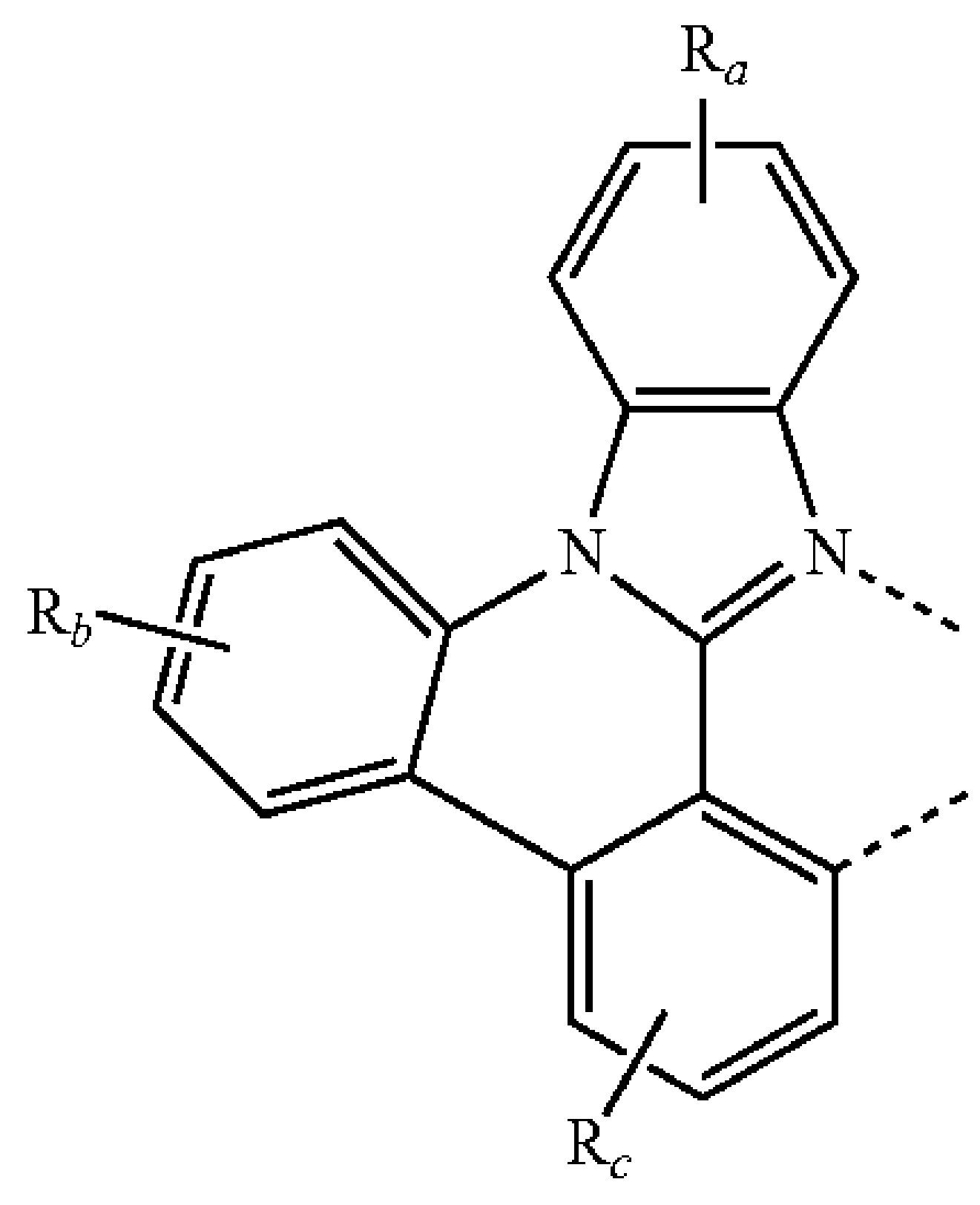
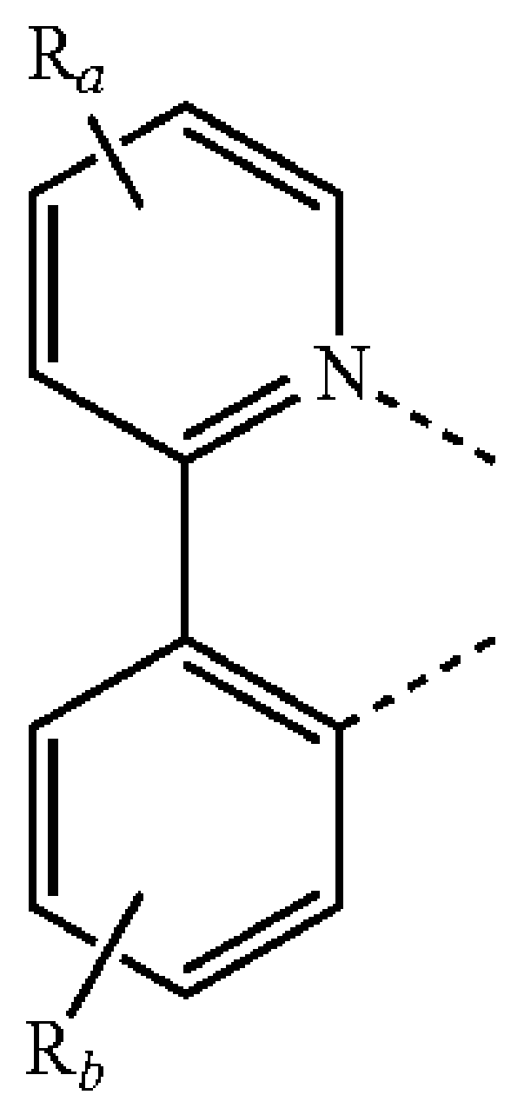
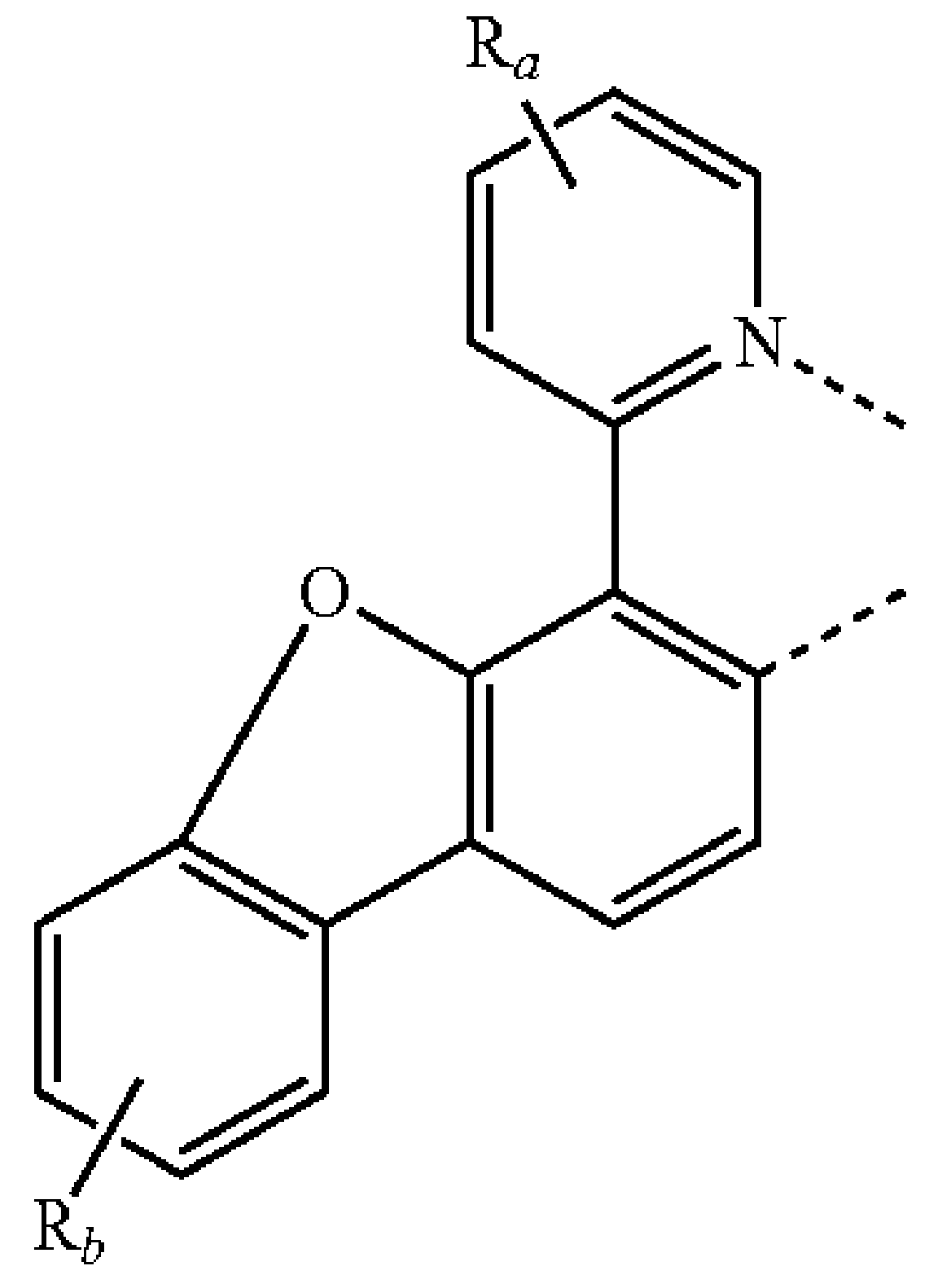
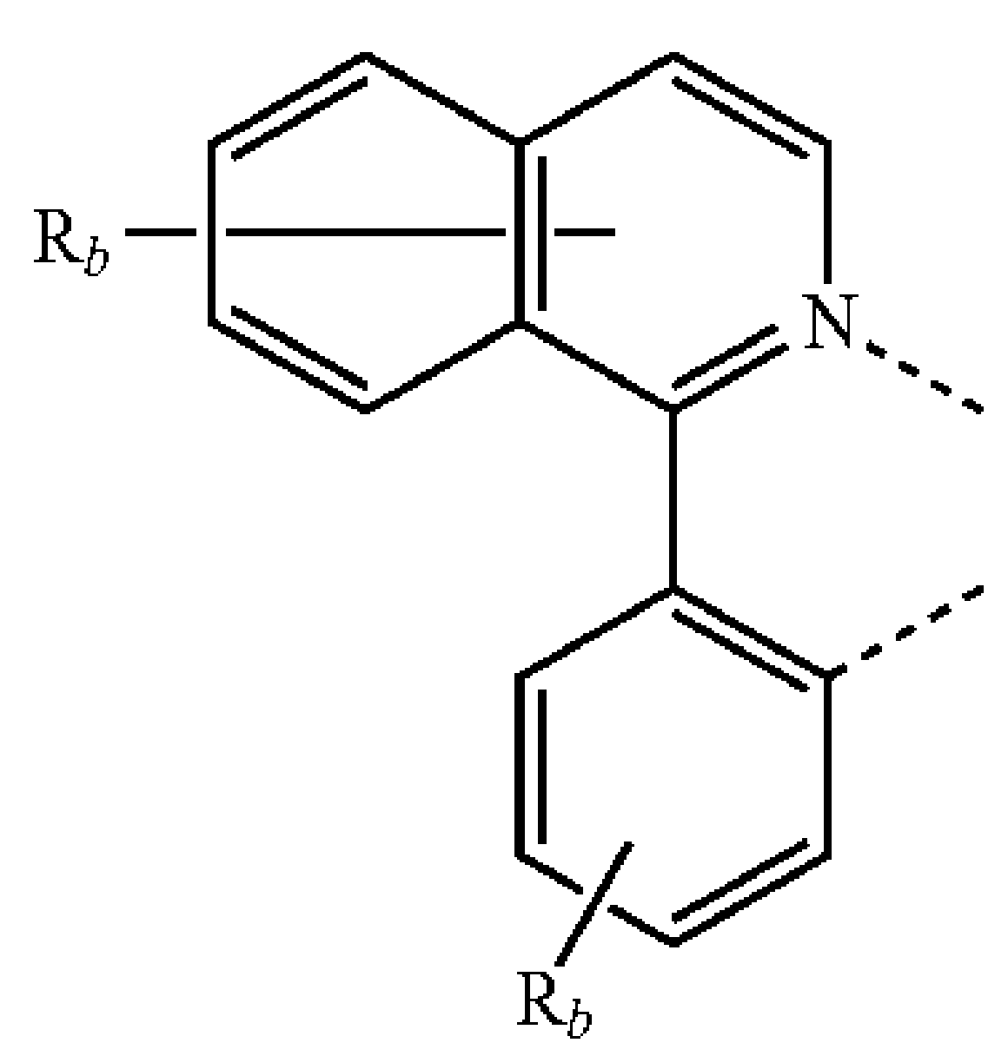
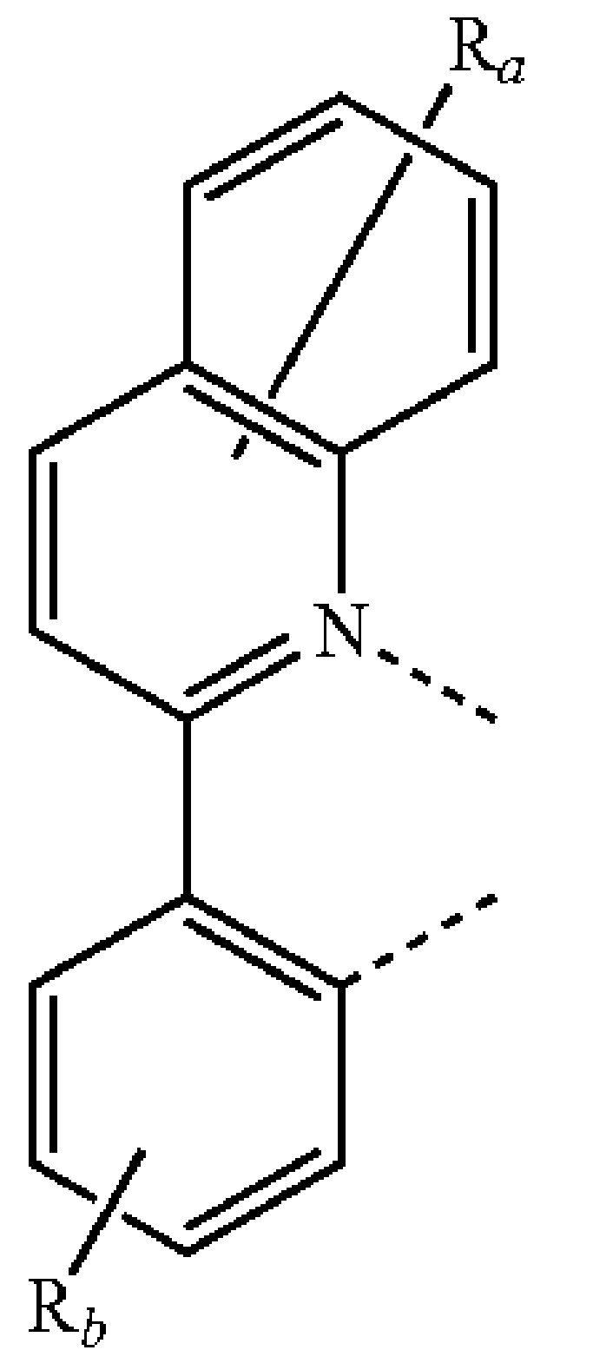
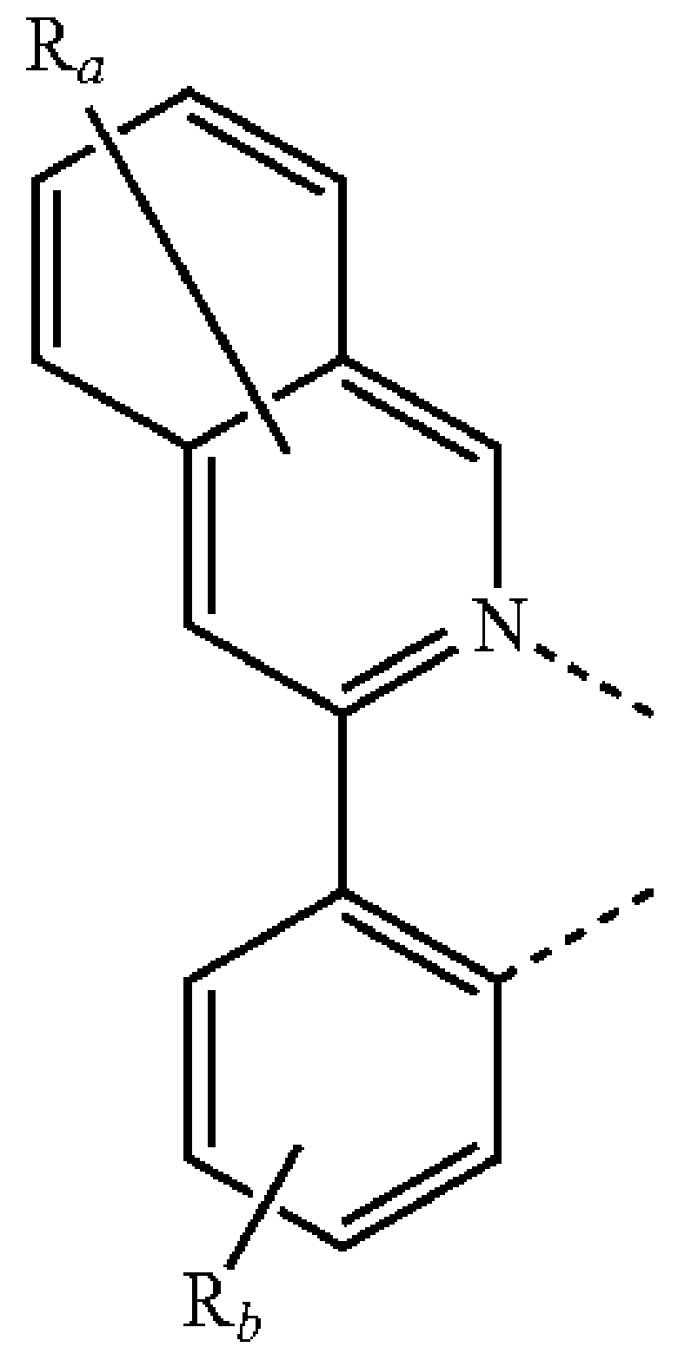
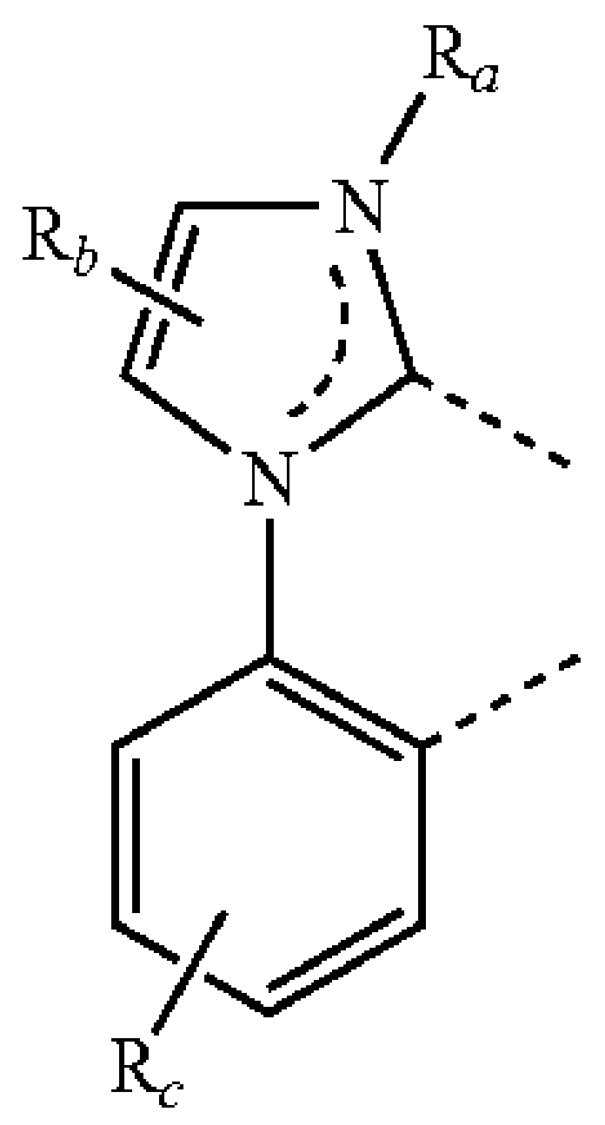
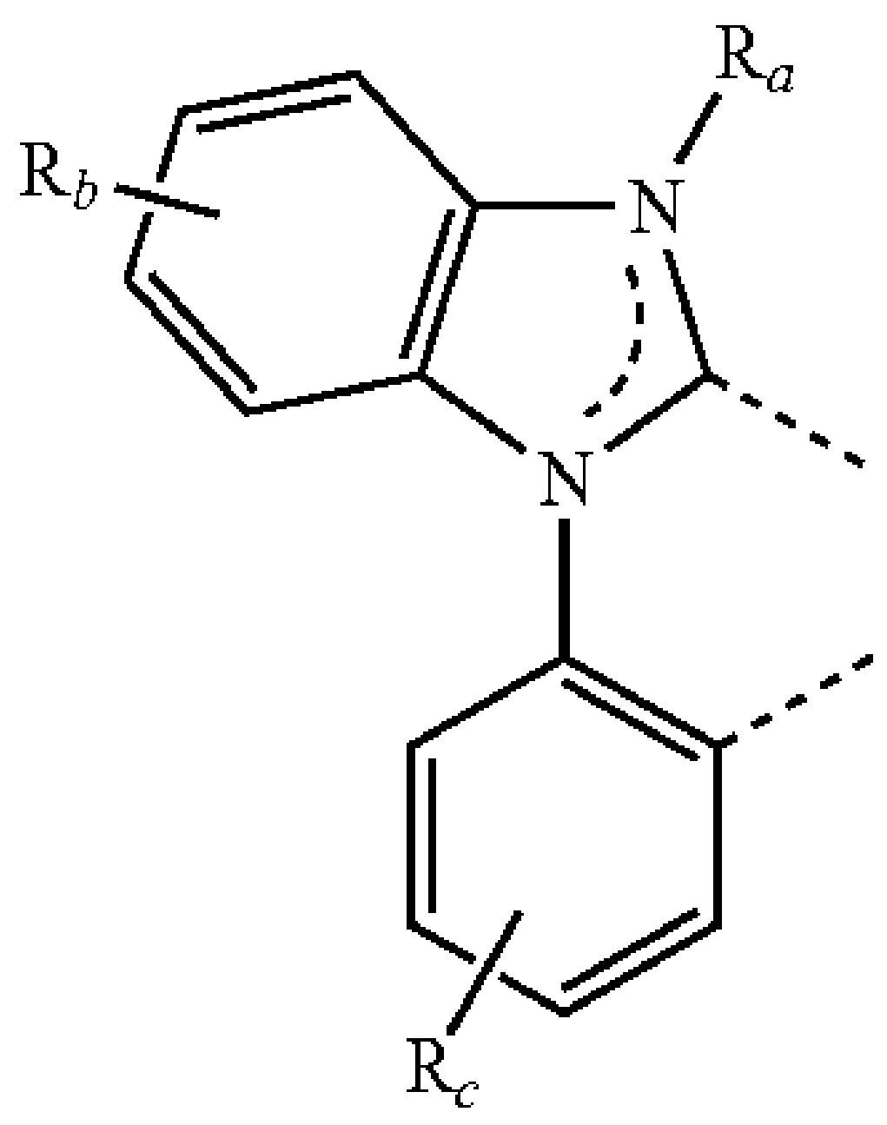
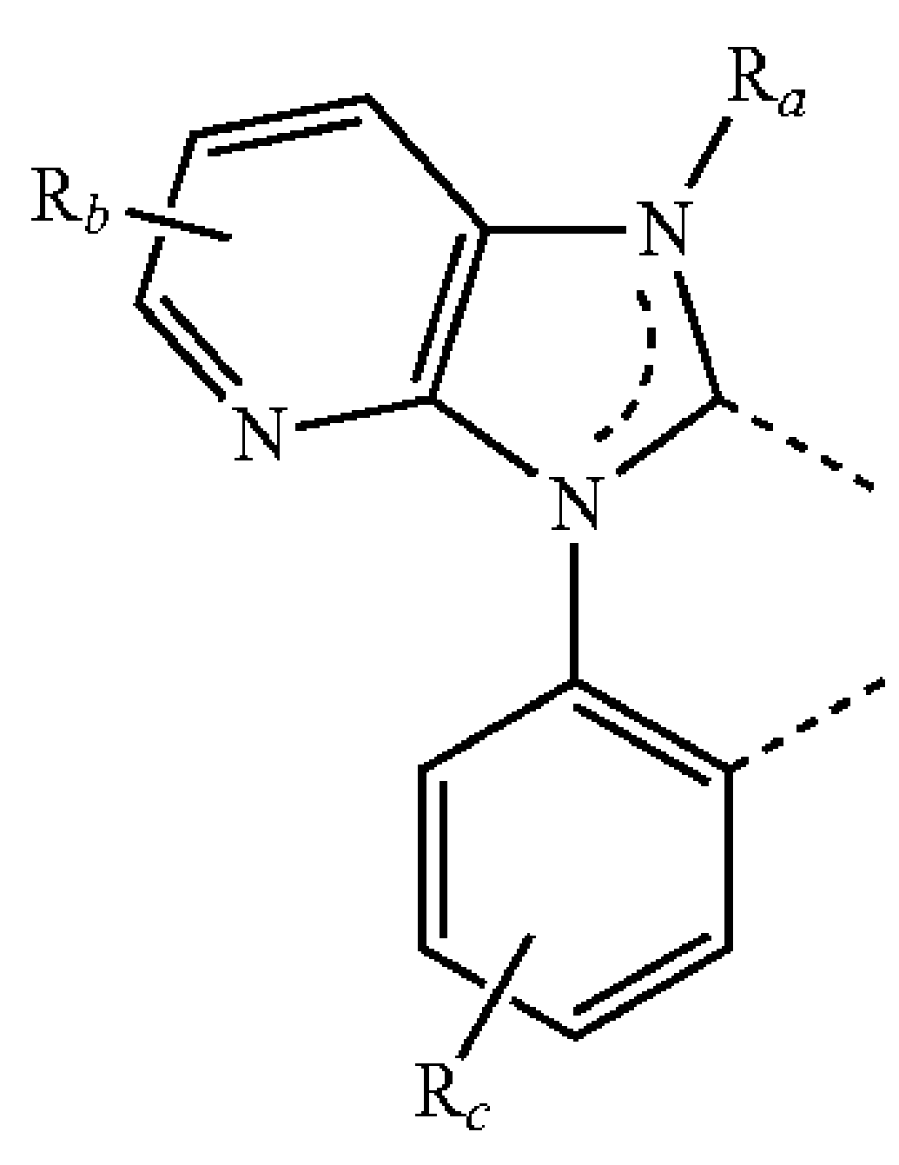
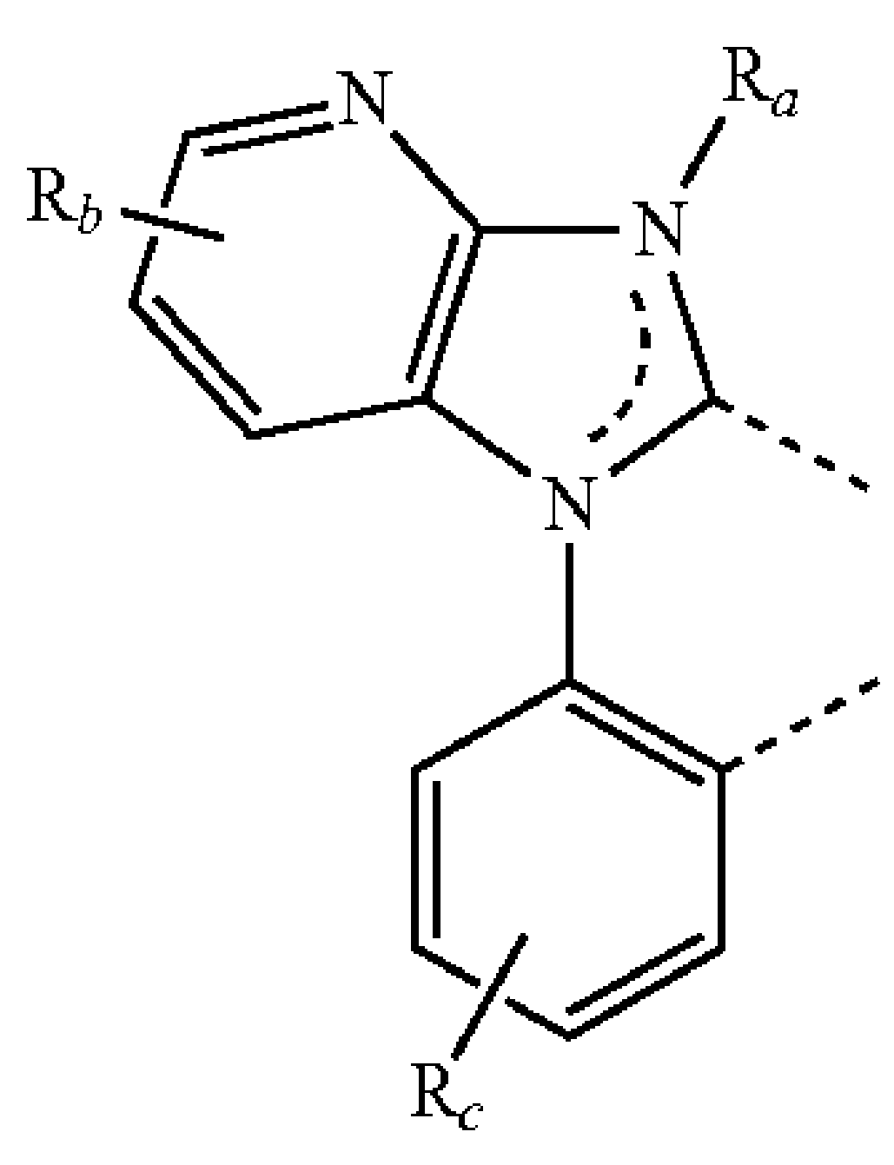

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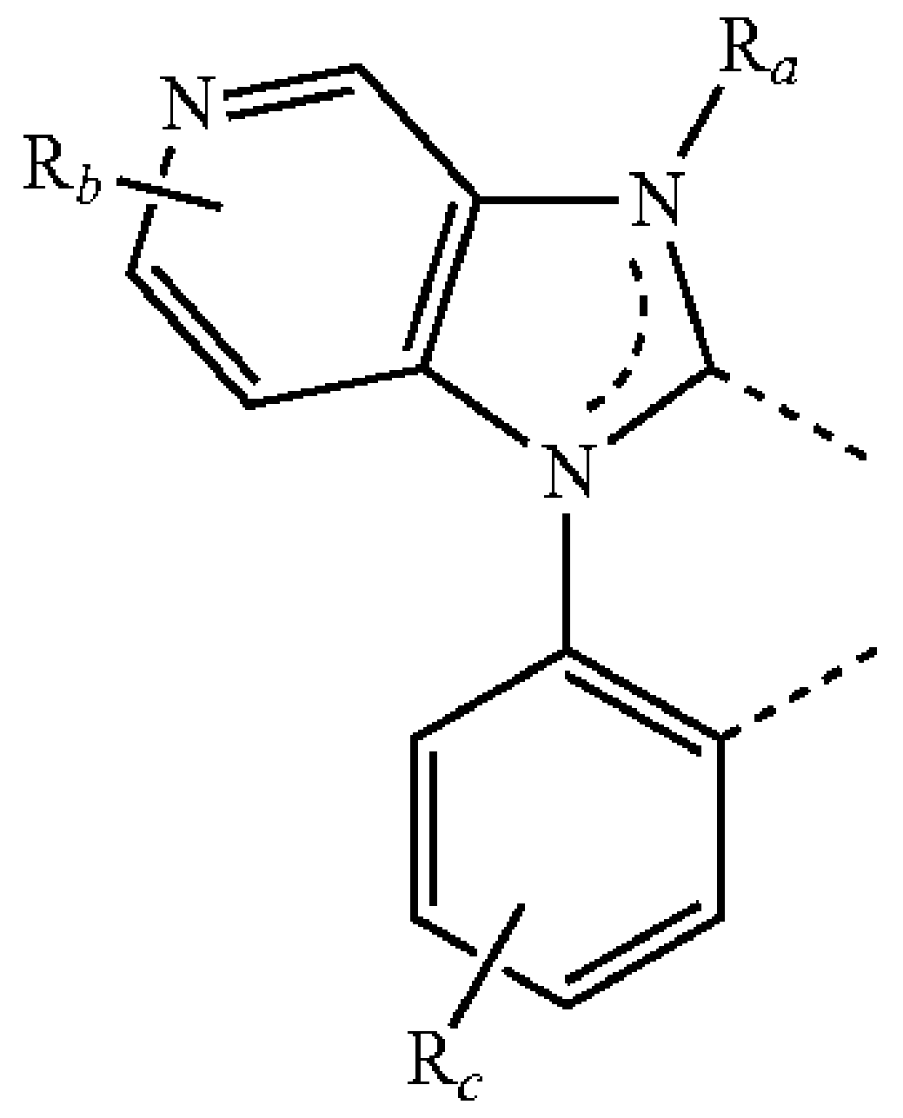
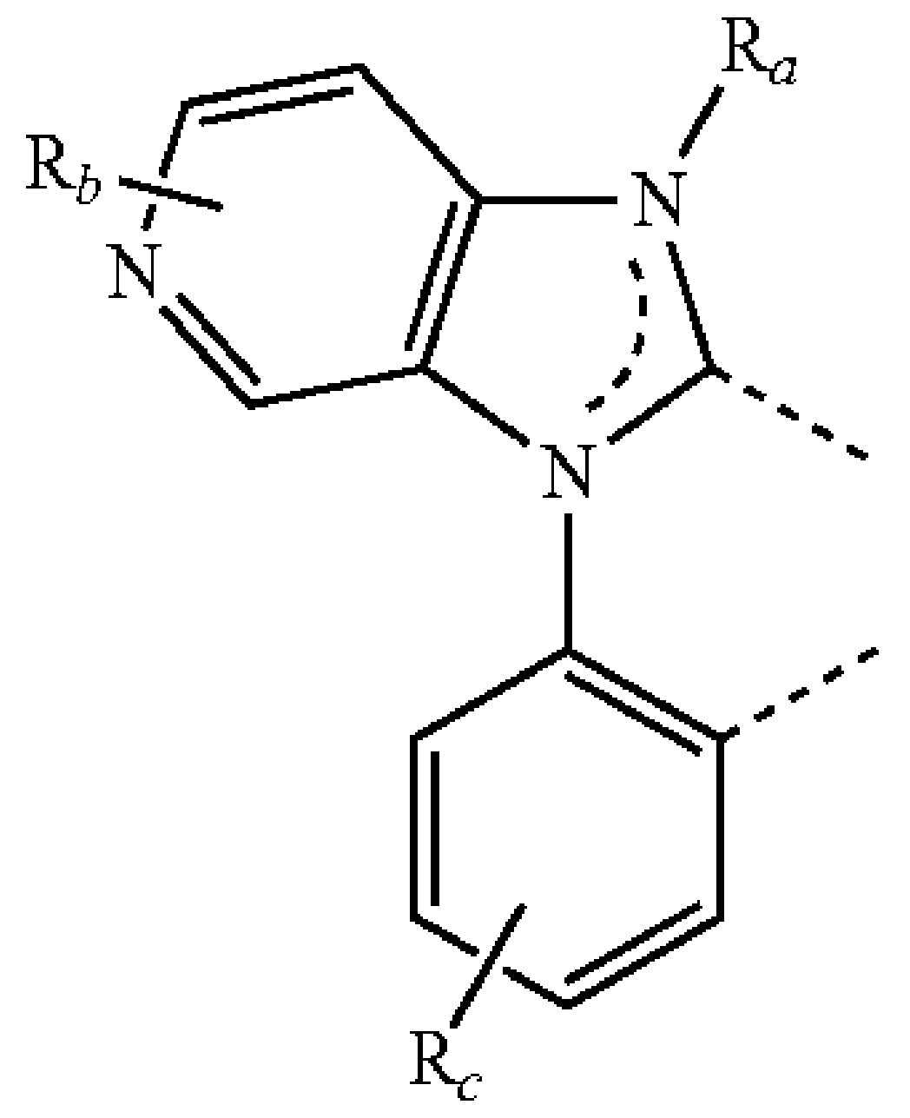
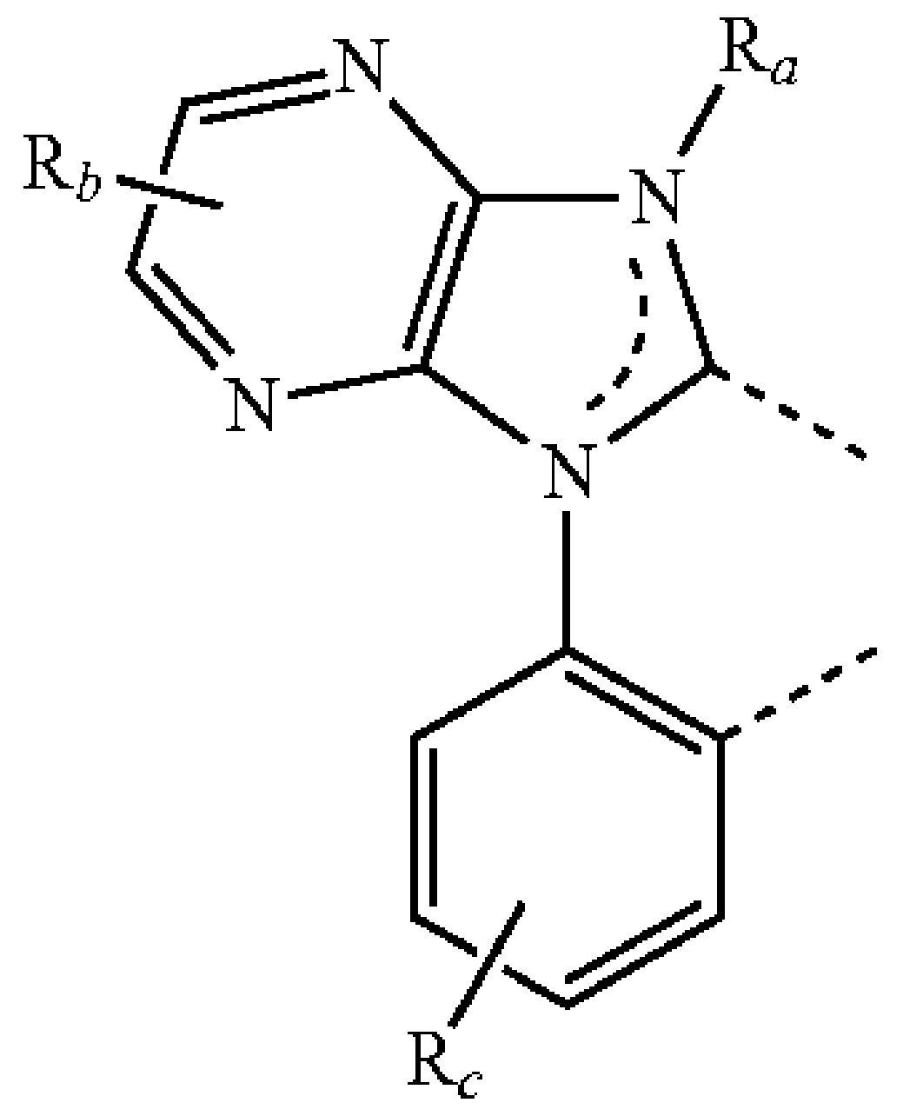
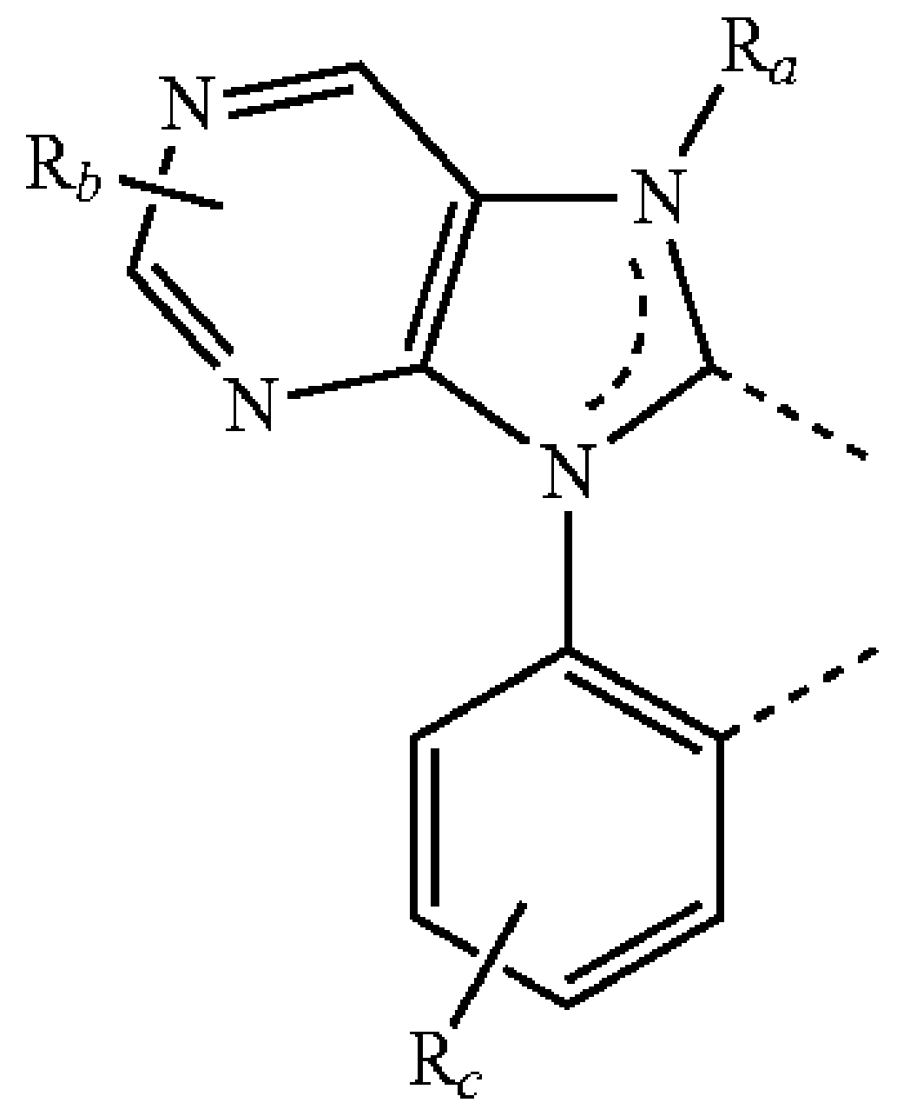
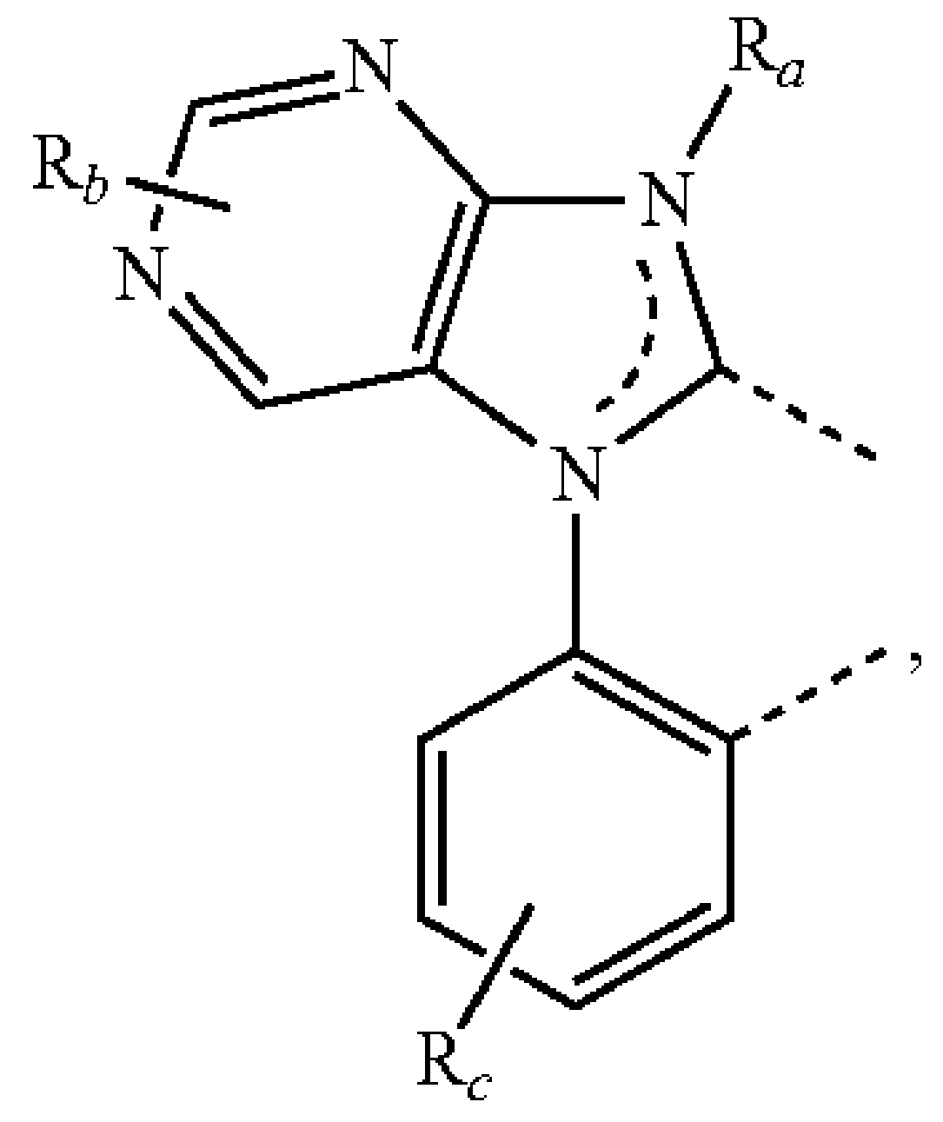
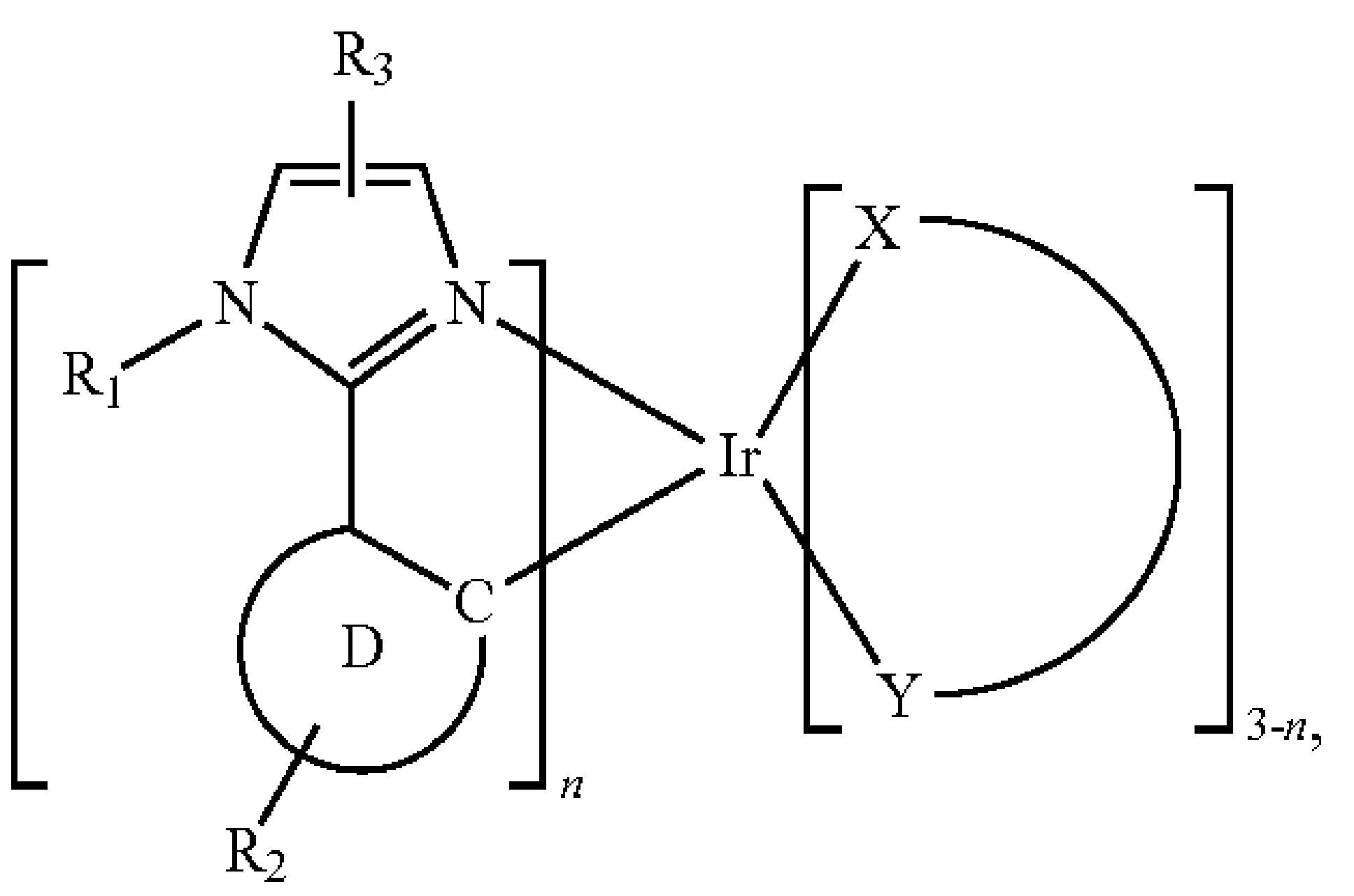






wherein R_a, R_b, and R_c may represent mono, di, tri or tetra substitutions;

wherein R_a, R_b, and R_c are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof; and

wherein two adjacent substituents of R_a, R_b, and R_c are optionally joined to form a fused ring.

17. The first device of claim **15**, wherein the emissive dopant has the formula



wherein D is a 5- or 6-membered carbocyclic or heterocyclic ring;

wherein R_1, R_2, and R_3 independently represent mono, di, tri or tetra substitution;

wherein each of R_1, R_2, and R_3 are independently selected from the group consisting of hydrogen, deuterium, halide, alkyl, cycloalkyl, heteroalkyl, arylalkyl, alkoxy, aryloxy, amino, silyl, alkenyl, cycloalkenyl, heteroalkenyl, alkynyl, aryl, heteroaryl, acyl, carbonyl, carboxylic acids, ester, nitrile, isonitrile, sulfanyl, sulfinyl, sulfonyl, phosphino, and combinations thereof;

wherein R_1 can be optionally linked to ring D;

wherein n is 1, 2, or 3; and wherein X—Y is another ligand.

18. The first device of claim **13**, wherein the device further comprises a second organic layer that is a non-emissive layer and the compound having Formula I is a material in the second organic layer.

19. The first device of claim **18**, wherein the second organic layer is a blocking layer and the compound having Formula I is a blocking material in the second organic layer.

20. The first device of claim **18**, wherein the second organic layer is an electron transporting layer and the compound having the Formula I is an electron transporting material in the second organic layer.

21. The first device of claim **13**, wherein the first device is a consumer product.

22. The first device of claim **13**, wherein the first device is an organic light-emitting device.

23. The first device of claim **14**, wherein the first device comprises a lighting panel.

* * * * *